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Data structure

Fenwick tree

```
template<typename T>
struct fenwick_tree {
    /* can convert it to map
     * build what you need only
     * will be: memory O(q*logn) ,time O(logn*logn) */
    vector<T> BIT;
    int n;
    fenwick_tree(int n) :
        n(n), BIT(n + 1) {
    }
    T getAccum(int idx) {
        T sum = 0;
        while (idx) {
            sum += BIT[idx];
            idx -= (idx & -idx);
        }
        return sum;
    }
    void add(int idx, T val) {
        assert(idx != 0);
        while (idx <= n) {
            BIT[idx] += val;
            idx += (idx & -idx);
        }
    }
    T getValue(int idx) {
        return getAccum(idx) - getAccum(idx - 1); }
    // ordered statistics tree
    // get index that has value >= accum
    // values must be positive
    int getIdx(T accum) {
        int start = 1, end = n, rt = -1;
        while (start <= end) {
            int mid = start + end >> 1;
            T val = getAccum(mid);
            if (val >= accum)
                rt = mid, end = mid - 1;
            else
                start = mid + 1;
        }
        return rt;
    }
    //need review (from topcoder)
    //first index less than or equal accum O(logn)
    int find(T accum) { //equal getIdx
        int i = 1, idx = 0;
        while ((1 << i) <= MAX)
            i <<= 1;
        for (idx = 0; i > 0; i >>= 1) {
            int tidx = idx + i;
            if (tidx > MAX)
                continue;
            if (accum >= BIT[tidx]) {
                idx = tidx;
                accum -= BIT[tidx];
            }
        }
    }
}
```

```

    }
    return idx;//idx+1 if you need first greater
}
};

```

Fenwick tree 2d

```

template<typename T>
struct fenwick_tree_2d {
#define Lbit(x) (x&-x)
    int n, m;
    vector<vector<T>>> BIT;
    fenwick_tree_2d(int n, int m) :
        n(n), m(m), BIT(n + 1, vector<T>(m + 1)) {
    }
    T getAccum(int i, int j) {
        T sum = 0;
        for (; i; i -= Lbit(i))
            for (int idx = j; idx > 0; idx -= Lbit(idx))
                sum += BIT[i][idx];
        return sum;
    }
    void add(int i, int j, int val) {
        assert(i != 0 && j != 0);
        for (; i <= n; i += Lbit(i))
            for (int idx = j; idx <= m; idx += Lbit(idx))
                BIT[i][idx] += val;
    }
    T getRectangleSum(int x1, int y1, int x2, int y2) {
        if (y1 > y2)
            swap(y1, y2);
        if (x1 > x2)
            swap(x1, x2);
        return getAccum(x2, y2) - getAccum(x1 - 1, y2) - getAccum(x2, y1 - 1)
            + getAccum(x1 - 1, y1 - 1);
    }
};

```

Fenwick tree max

```

//fenwick tree for get maximum from 1 to idx
// update a[idx] = max(a[idx],val)
//can't remove values
template<typename T>
struct fenwick_tree {
    vector<T> BIT;
    int n;
    fenwick_tree(int n) :
        n(n), BIT(n + 1) {
    }
    T getMax(int idx) {
        T mx = numeric_limits<T>::min();
        while (idx) {
            mx = max(mx, BIT[idx]);
            idx -= (idx & -idx);
        }
        return mx;
    }
    void add(int idx, T val) {
        assert(idx != 0);
        while (idx <= n) {
            BIT[idx] = max(BIT[idx], val);
            idx += (idx & -idx);
        }
    }
};

```

```
};
```

Fenwick tree update range

```
/*
x[i] = a[i] - a[i-1] //a is original array
y[i] = x[i]*(i-1)

sum(1,3) = a[1] + a[2] + a[3] = (x[1]) + (x[2] + x[1]) + (x[3] + x[2] + x[1])

= 3*(x[1] + x[2] + x[3]) - 0*x[1] - 1*x[2] - 2*x[3] //same equation but more complex
= sumX(1,3) * 3 - sumY(1,3)
so sum(1,n) = sumX(1,n)*n - sumY(1,n)

update:
x[l] += val, x[r+1] -= val
y[l] += val * (l-1), y[r+1] -= r*val
*/

template<typename T>
class fenwick_tree {
    int n;
    vector<T> x, y;
    T getAccum(vector<T>& BIT, int idx) {
        T sum = 0;
        while (idx) {
            sum += BIT[idx];
            idx -= (idx & -idx);
        }
        return sum;
    }
    void add(vector<T>& BIT, int idx, T val) {
        assert(idx != 0);
        while (idx <= n) {
            BIT[idx] += val;
            idx += (idx & -idx);
        }
    }
    T prefix_sum(int idx) {
        return getAccum(x, idx) * idx - getAccum(y, idx);
    }
public:
    fenwick_tree(int n) :
        n(n), x(n + 1), y(n + 1) {}
    void update_range(int l, int r, T val) {
        add(x, l, val);
        add(x, r + 1, -val);
        add(y, l, val * (l - 1));
        add(y, r + 1, -val * r);
    }
    T range_sum(int l, int r) {
        return prefix_sum(r) - prefix_sum(l - 1);
    }
};
```

Segment tree

```
/*
for efficient memory (2*n)
#define LEFT (idx<<1)
#define MID ((start+end)>>1)
#define RIGHT (idx+((MID-start+1)<<1))
*/
template<typename node> class segment_tree {
#define LEFT (idx<<1)
#define RIGHT (idx<<1|1)
#define MID ((start+end)>>1)
    int left_range, right_range;
    vector<node> tree;
    inline void pushup(int idx) {
        tree[idx] = node(tree[LEFT], tree[RIGHT]);
    }
    inline void pushdown(int idx, int start, int end) {
        if (!tree[idx].have_lazy || start == end)
            return;
        tree[LEFT].apply(start, MID, tree[idx].lazy_value);
        tree[RIGHT].apply(MID + 1, end, tree[idx].lazy_value);
        tree[idx].clear_lazy();
    }
    void build(int idx, int start, int end) {
        if (start == end)
            return;
        build(LEFT, start, MID);
        build(RIGHT, MID + 1, end);
        pushup(idx);
    }
    template<typename T>
    void build(int idx, int start, int end, const vector<T>& arr) {
        if (start == end) {
            tree[idx] = arr[start];
            return;
        }
        build(LEFT, start, MID, arr);
        build(RIGHT, MID + 1, end, arr);
        pushup(idx);
    }
    node query(int idx, int start, int end, int from, int to) {
        if (from <= start && end <= to)
            return tree[idx];
        pushdown(idx, start, end);
        if (to <= MID)
            return query(LEFT, start, MID, from, to);
        if (MID < from)
            return query(RIGHT, MID + 1, end, from, to);
        return node(query(LEFT, start, MID, from, to),
            query(RIGHT, MID + 1, end, from, to));
    }
    template<typename ... T>
    void update(int idx, int start, int end, int from, int to, const T&... val) {
        if (to < start || end < from)
            return;
        if (from <= start && end <= to) {
            tree[idx].apply(start, end, val...);
            return;
        }
    }
};
```



```

        pushdown(idx, start, end);
        update(LEFT, start, MID, from, to, val...);
        update(RIGHT, MID + 1, end, from, to, val...);
        pushup(idx);
    }
    void init(int l, int r) {
        left_range = l;
        right_range = r;
        tree = vector < node >((r - l + 1) << 2);
    }
public:
    segment_tree(int l, int r) {
        init(l, r);
        build(1, l, r);
    }
    template<typename T>
    segment_tree(int l, int r, const vector<T>& v) {
        init(l, r);
        build(1, l, r, v);
    }
    node query(int l, int r) {
        assert(left_range <= l && l <= r && r <= right_range);
        return query(1, left_range, right_range, l, r);
    }
    template<typename ... T>
    void update(int l, int r, const T&... val) {
        assert(left_range <= l && l <= r && r <= right_range);
        update(1, left_range, right_range, l, r, val...);
    }
#undef LEFT
#undef RIGHT
#undef MID
};

```

Iterative Segment tree

```

struct node {
    node() { //set Default value
    }
    node(const node& a, const node& b) {}
    void apply(int val) {}
};
struct segment_tree {
    int n; //0 to n-1
    vector<node> tree;
    segment_tree(int n) {
        resize(n);
        build();
    }
    template<typename T>
    segment_tree(const vector<T>& arr) {
        resize(arr.size());
        for (int i = 0; i < arr.size(); i++)
            tree[n + i] = arr[i];
        build();
    }
    void resize(int n) {
        int p = 1;
        while (p < n)
            p <<= 1;
        this->n = p;
        tree = vector < node >(p << 1);
    }
    void build() {
        for (int i = n - 1; i > 0; i--)

```

```

        tree[i] = node(tree[i << 1], tree[i << 1 | 1]);
    }

template<typename T>
void update(int p, const T& value) {
    tree[p += n].apply(value);
    for (int i = p / 2; i > 0; i >>= 1)
        tree[i] = node(tree[i << 1], tree[i << 1 | 1]);
}

node query(int l, int r) { // [l, r]
    node resl, resr; // set default value in node
    for (l += n, r += n + 1; l < r; l >>= 1, r >>= 1) {
        if (l & 1) {
            resl = node(resl, tree[l]);
            l++;
        }
        if (r & 1) {
            r--;
            resr = node(tree[r], resr);
        }
    }
    return node(resl, resr);
}

int kth_one(int k, int i = 1) {
    if (k > tree[i])
        return -1;
    if (i >= n)
        return i - n;
    if (tree[i << 1] >= k)
        return kth_one(k, i << 1);
    return kth_one(k - tree[i << 1], i << 1 | 1);
}

};

```

Max sum range node

```

struct MSR_Node {
    ll left, right, mid, sum;
    MSR_Node(const ll& val) {
        left = right = mid = sum = val;
    }
    MSR_Node(const MSR_Node& a, const MSR_Node& b) {
        left = max(a.left, a.sum + b.left);
        right = max(b.right, b.sum + a.right);
        mid = max({ a.mid, b.mid, a.right + b.left });
        sum = a.sum + b.sum;
    }
    ll getMax() {
        return max({ left, right, mid, sum });
    }
};

```

Persistent segment tree

```

struct segtree {
    static segtree *sentinel;
    segtree *left, *right;
    bool dirty = false;
    ll sum = 0;
    ll lazy = 0;
};

```

```

segtree(ll val = 0) :
    sum(val) {
        left = right = this;
    }
segtree(segtree *left, segtree *right) :
    left(left), right(right) {
        sum = left->sum + right->sum;
    }
};

segtree *segtree::sentinel = new segtree();

```

```

class persistent_segment_tree {
#define MID ((start+end)>>1)
    segtree* apply(segtree *root, int start, int end, ll val) {
        segtree *rt = new segtree(*root);
        rt->dirty = true;
        rt->sum += (end - start + 1) * val;
        rt->lazy += val;
        return rt;
    }
    void pushdown(segtree *root, int start, int end) {
        if (root->dirty == false || start == end)
            return;
        root->left = apply(root->left, start, MID, root->lazy);
        root->right = apply(root->right, MID + 1, end, root->lazy);
        root->lazy = 0;
        root->dirty = 0;
    }
    segtree* build(int start, int end, const vector<int> &v) {
        if (start == end)
            return new segtree(v[start]);
        return new segtree(build(start, MID, v), build(MID + 1, end, v));
    }
    segtree* Set(segtree *root, int start, int end, int pos, ll new_val) {
        pushdown(root, start, end);
        if (pos < start || end < pos)
            return root;
        if (pos <= start && end <= pos)
            return new segtree(new_val);
        return new segtree(Set(root->left, start, MID, pos, new_val),
            Set(root->right, MID + 1, end, pos, new_val));
    }
    segtree* update(segtree *root, int start, int end, int l, int r, ll val) {
        pushdown(root, start, end);
        if (r < start || end < l)
            return root;
        if (l <= start && end <= r)
            return apply(root, start, end, val);
        return new segtree(update(root->left, start, MID, l, r, val),
            update(root->right, MID + 1, end, l, r, val));
    }
}

```

```

ll query(segtree *root, int start, int end, int l, int r) {
    pushdown(root, start, end);
    if (r < start || end < l)
        return 0;
    if (l <= start && end <= r)
        return root->sum;
    return query(root->left, start, MID, l, r)
        + query(root->right, MID + 1, end, l, r);
}

public:
    int start, end;
    vector<segtree*> versions;
    persistent_segment_tree(int start, int end) :
        start(start), end(end) {
        versions.push_back(segtree::sentinel);
    }
    persistent_segment_tree(const vector<int> &v) :
        start(0), end(v.size() - 1) {
        versions.push_back(build(start, end, v));
    }
    void update(int l, int r, ll val) {
        versions.push_back(update(versions.back(), start, end, l, r, val));
    }
    ll query(int time, int l, int r) {
        return query(versions[time], start, end, l, r);
    }
}

#undef MID
};

```

Extended Segment tree

```

struct segtree {
    segtree *left = nullptr, *right = nullptr;
    int mx = 0;
    segtree(int val = 0) :
        mx(val) {
    }
    void extend() {
        if (left == NULL) {
            left = new segtree();
            right = new segtree();
        }
    }
    void pushup() {
        mx = max(left->mx, right->mx);
    }
};

class extened_segment_tree {
#define MID ((start+end)>>1)
    void update(segtree *root, int start, int end, int pos, int val) {
        if (pos < start || end < pos)
            return;
    }
};

```

```

    if (start == end) {
        root->mx = max(root->mx, val);
        return;
    }
    root->extend();
    update(root->left, start, MID, pos, val);
    update(root->right, MID + 1, end, pos, val);
    root->pushup();
}
int query(segtree *root, int start, int end, int l, int r) {
    if (root == nullptr || r < start || end < l)
        return 0;
    if (l <= start && end <= r)
        return root->mx;
    return max(query(root->left, start, MID, l, r),
               query(root->right, MID + 1, end, l, r));
}
public:
    int start, end;
    segtree *root;
    extened_segment_tree() {
    }
    extened_segment_tree(int start, int end) :
        start(start), end(end) {
        root = new segtree();
    }
    void update(int pos, int val) {
        update(root, start, end, pos, val);
    }
    int query(int l, int r) {
        return query(root, start, end, l, r);
    }
}
#undef MID
};

```

Ordered set

```

#include<bits/stdc++.h>
#include<ext/pb_ds/assoc_container.hpp>
#include<ext/pb_ds/tree_policy.hpp>
using namespace std;
using namespace __gnu_pbds;
template<typename key>
using ordered_set = tree<key, null_type, less<key>, rb_tree_tag, tree_order_statistics_node_update>;
/*
    find_by_order(k) :
    It returns to an iterator to the k-th element (counting from zero) in the set in O(logn) time.
    To find the first element k must be zero.
    order_of_key(k) :
    It returns to the number of items that are strictly smaller than our item k in O(logn) time.
*/

```

Sparse table

```

template<typename T>
struct sparse_table {
    vector<vector<T>> sparseTable;

```

```

using F = function<T(T, T)>;
F merge;
static int LOG2(int x) { //floor(log2(x))
    return 31 - __builtin_clz(x);
}
sparse_table(vector<T>& v, F merge) :
    merge(merge) {
        int n = v.size();
        int logN = LOG2(n);
        sparseTable = vector<vector<T>>(logN + 1);
        sparseTable[0] = v;
        for (int k = 1, len = 1; k <= logN; k++, len <= 1) {
            sparseTable[k].resize(n);
            for (int i = 0; i + len < n; i++)
                sparseTable[k][i] = merge(sparseTable[k - 1][i],
                    sparseTable[k - 1][i + len]);
        }
    }
T query(int l, int r) {
    int k = LOG2(r - l + 1); // max k ==> 2^k <= length of range
    //check first 2^k from left and last 2^k from right //overlap
    return merge(sparseTable[k][l], sparseTable[k][r - (1 << k) + 1]);
}
T query_shifting(int l, int r) {
    T res;
    bool first = true;
    for (int i = (int)sparseTable.size() - 1; i >= 0; i--)
        if (l + (1 << i) - 1 <= r) {
            if (first)
                res = sparseTable[i][l];
            else
                res = merge(res, sparseTable[i][l]);
            first = false;
            l += (1 << i);
        }
    return res;
}
};

```

SQRT Decomposition

```

//zero based SQRT_Decomposition with lazy propagation
template<typename update_type, typename query_type>
class SQRT_Decomposition {
    struct Bucket {
        int l, r;
        update_type lazy;
        Bucket(int l, int r) :
            l(l), r(r) {
                //set default value to lazy
                //build bucket for the first time
            }
        void build() {
            //update all bucket with lazy if have
            //rebuild the bucket
            //clear lazy
        }
        //update all bucket
        void update(const update_type& val) {
            //just update lazy
        }
    }
};

```

```

//update range in bucket
void update(int start, int end, const update_type& val) {
    if (start == 1 && end == r) {
        update(val);
        return;
    }
    //update bucket
    //rebuild the bucket if need
}
//query about all bucket
query_type query() {
    //calc with lazy
}
//query about range in bucket
query_type query(int start, int end) {
    if (start == 1 && end == r)
        return query();
    //push lazy if have
    //calc
}
};

int n, sqrtN;
vector<Bucket> bucket;
int begin(int idx) {
    return idx * sqrtN;
}
int end(int idx) {
    return min(sqrtN * (idx + 1), n) - 1;
}
int which_block(int idx) {
    return idx / sqrtN;
}

public:
SqrtDecomposition(int n) {
    this->n = n;
    sqrtN = sqrt(n);
    for (int i = 0; i < n; i += sqrtN)
        bucket.push_back(Bucket(i, min(i + sqrtN, n) - 1));
}

void update(int left, int right, update_type val) {
    int st = which_block(left), ed = which_block(right);
    bucket[st].update(left, min(bucket[st].r, right), val);
    for (int i = st + 1; i < ed; i++)
        bucket[i].update(val);
    if (st != ed)
        bucket[ed].update(bucket[ed].l, right, val);
}

query_type query(int left, int right) {
    int st = which_block(left), ed = which_block(right);
    query_type rt = bucket[st].query(left, min(bucket[st].r, right));
    for (int i = st + 1; i < ed; i++)
        rt += bucket[i].query();
    if (st != ed)
        rt += bucket[ed].query(bucket[ed].l, right);
    return rt;
}

```

```
};
```

Implicit treap

```
enum DIR {
    L, R
};

template<typename T>
struct cartesian_tree {
    static cartesian_tree<T>* sentinel;
    T key;
    int priority = 0, size = 0;
    bool reverse = false;
    cartesian_tree* child[2];
    cartesian_tree() {
        key = T();
        priority = 0;
        child[L] = child[R] = this;
    }
    cartesian_tree(const T& x, int y) :
        key(x), priority(y) {
        size = 1;
        child[L] = child[R] = sentinel;
    }
    void push_down() {
        if (!reverse)
            return;
        reverse = 0;
        child[L]->doReverse();
        child[R]->doReverse();
    }
    void doReverse() {
        reverse ^= 1;
        swap(child[L], child[R]);
    }
    void push_up() {
        size = child[L]->size + child[R]->size + 1;
    }
};

template<typename T>
cartesian_tree<T>* cartesian_tree<T>::sentinel = new cartesian_tree<T>();

template<typename T, template<typename > class cartesian_tree>
class implicit_treap { //1 based
    typedef cartesian_tree<T> node;
    typedef cartesian_tree<T>* nodeptr;
#define emptyNode cartesian_tree<T>::sentinel
    nodeptr root;
    void split(nodeptr root, nodeptr& l, nodeptr& r, int firstXElement) {
        if (root == emptyNode) {
            l = r = emptyNode;
            return;
        }
        root->push_down();
        if (firstXElement <= root->child[L]->size) {
            split(root->child[L], l, root->child[L], firstXElement);
            r = root;
        }
        else {
            split(root->child[R], root->child[R], r,

```



```

        firstXElement - root->child[L]->size - 1);
        l = root;
    }
    root->push_up();
}

nodeptr merge(nodeptr l, nodeptr r) {
    l->push_down();
    r->push_down();
    if (l == emptyNode || r == emptyNode)
        return (l == emptyNode ? r : l);
    if (l->priority > r->priority) {
        l->child[R] = merge(l->child[R], r);
        l->push_up();
        return l;
    }
    r->child[L] = merge(l, r->child[L]);
    r->push_up();
    return r;
}

vector<nodeptr> split_range(int s, int e) { // [x<s,s<=x<=e,e<x]
    nodeptr l, m, r, tmp;
    split(root, l, tmp, s - 1);
    split(tmp, m, r, e - s + 1);
    return { l,m,r };
}

public:
    implicit_treap() :
        root(emptyNode) {
    }
    int size() {
        return root->size;
    }
    void insert(int pos, const T& key) {
        nodeptr tmp = new node(key, rand());
        nodeptr l, r;
        split(root, l, r, pos - 1);
        root = merge(merge(l, tmp), r);
    }
    void push_back(const T& value) {
        root = merge(root, new node(value, rand()));
    }
    T getByIndex(int pos) {
        vector<nodeptr> tmp = split_range(pos, pos);
        nodeptr l = tmp[0], m = tmp[1], r = tmp[2];
        T rt = m->key;
        root = merge(merge(l, m), r);
        return rt;
    }
    void erase(int pos) {
        vector<nodeptr> tmp = split_range(pos, pos);
        nodeptr l = tmp[0], m = tmp[1], r = tmp[2];
        delete m;
        root = merge(l, r);
    }
    void cyclic_shift(int s, int e) { //to the right
        vector<nodeptr> tmp = split_range(s, e);
        nodeptr l = tmp[0], m = tmp[1], r = tmp[2];
        nodeptr first, second;
        split(m, first, second, e - s);
        root = merge(merge(merge(l, second), first), r);
    }
    void reverse_range(int s, int e) {
        vector<nodeptr> tmp = split_range(s, e);

```

```

        nodeptr l = tmp[0], m = tmp[1], r = tmp[2];
        m->reverse ^= 1;
        root = merge(merge(l, m), r);
    }

    node range_query(int s, int e) {
        vector<nodeptr> tmp = split_range(s, e);
        nodeptr l = tmp[0], m = tmp[1], r = tmp[2];
        node rt = *m;
        root = merge(merge(l, m), r);
        return rt;
    }
};

```

Ordered multiset

```

enum DIR {
    L, R
};

template<typename T>
struct cartesian_tree {
    static cartesian_tree<T>* sentinel;
    T key;
    int priority = 0, frequency = 0, size = 0;
    cartesian_tree* child[2];
    cartesian_tree() {
        key = T();
        priority = 0;
        child[L] = child[R] = this;
    }
    cartesian_tree(const T& x, int y) :
        key(x), priority(y) {
        size = frequency = 1;
        child[L] = child[R] = sentinel;
    }
    void push_down() {
    }
    void push_up() {
        size = child[L]->size + child[R]->size + frequency;
    }
};

template<typename T>
cartesian_tree<T>* cartesian_tree<T>::sentinel = new cartesian_tree<T>();

template<typename T>
void split(cartesian_tree<T>* root, T key, cartesian_tree<T>*& l,
    cartesian_tree<T>*& r) {
    if (root == cartesian_tree<T>::sentinel) {
        l = r = cartesian_tree<T>::sentinel;
        return;
    }
    root->push_down();
    if (root->key <= key) {
        split(root->child[R], key, root->child[R], r);
        l = root;
    }
    else {
        split(root->child[L], key, l, root->child[L]);
        r = root;
    }
    root->push_up();
}

```

```

template<typename T>
cartesian_tree<T>* merge(cartesian_tree<T>* l, cartesian_tree<T>* r) {
    l->push_down();
    r->push_down();
    if (l == cartesian_tree<T>::sentinel || r == cartesian_tree<T>::sentinel)
        return (l == cartesian_tree<T>::sentinel ? r : l);
    if (l->priority > r->priority) {
        l->child[R] = merge(l->child[R], r);
        l->push_up();
        return l;
    }
    r->child[L] = merge(l, r->child[L]);
    r->push_up();
    return r;
}

```

```

template<typename T, template<typename > class cartesian_tree>
class treap {
    typedef cartesian_tree<T> node;
    typedef node* nodeptr;
#define emptyNode node::sentinel
    nodeptr root;
    void insert(nodeptr& root, nodeptr it) {
        if (root == emptyNode) {
            root = it;
        }
        else if (it->priority > root->priority) {
            split(root, it->key, it->child[L], it->child[R]);
            root = it;
        }
        else
            insert(root->child[root->key < it->key], it);
        root->push_up();
    }
    bool increment(nodeptr root, const T& key) {
        if (root == emptyNode)
            return 0;
        if (root->key == key) {
            root->frequency++;
            root->push_up();
            return root;
        }
        bool rt = increment(root->child[root->key < key], key);
        root->push_up();
        return rt;
    }
    nodeptr find(nodeptr root, const T& key) {
        if (root == emptyNode || root->key == key)
            return root;
        return find(root->child[root->key < key], key);
    }
    void erase(nodeptr& root, const T& key) {
        if (root == emptyNode)
            return;
        if (root->key == key) {
            if (--(root->frequency) == 0)
                root = merge(root->child[L], root->child[R]);
        }
        else

```

```

        erase(root->child[root->key < key], key);
    root->push_up();
}

T kth(nodeptr root, int k) {
    if (root->child[L]->size >= k)
        return kth(root->child[L], k);
    k -= root->child[L]->size;
    if (k <= root->frequency)
        return root->key;
    return kth(root->child[R], k - root->frequency);
}

int order_of_key(nodeptr root, const T& key) {
    if (root == emptyNode)
        return 0;
    if (key < root->key)
        return order_of_key(root->child[L], key);
    if (key == root->key)
        return root->child[L]->size;
    return root->child[L]->size + root->frequency
        + order_of_key(root->child[R], key);
}

public:
    treap() :
        root(emptyNode) {
    }
    void insert(const T& x) {
        if (increment(root, x)) //change it to find(x) to make it as a set
            return;
        insert(root, new node(x, rand()));
    }
    void erase(const T& x) {
        erase(root, x);
    }
    bool find(const T& x) {
        return (find(root, x) != emptyNode);
    }
    int get_kth_number(int k) {
        assert(1 <= k && k <= size());
        return kth(root, k);
    }
    int order_of_key(const T& x) {
        return order_of_key(root, x);
    }
    int size() {
        return root->size;
    }
};

```

BST

```

class BST {
    struct node {
        int key;
        node* left, * right, * parent;
        node() {
            key = 0;
            left = right = parent = NULL;
        }
        node(int key, node* left = NULL, node* right = NULL, node* parent = NULL) :
            key(key), left(left), right(right), parent(parent) {
        }
    };
};

```

```

typedef node* nodeptr;
nodeptr minimum(nodeptr root) {
    if (root->left == NULL)
        return root;
    return minimum(root->left);
}
nodeptr maximum(nodeptr root) {
    if (root->right == NULL)
        return root;
    return maximum(root->right);
}
nodeptr successor(nodeptr cur) { //smallest key larger than cur
    if (cur->right != NULL)
        return minimum(cur->right);
    nodeptr tmp = cur->parent;
    while (tmp != NULL && tmp->right == cur)
        cur = tmp, tmp = tmp->parent;
    return tmp;
}
nodeptr bredecessor(nodeptr cur) { //biggest key less than cur
    if (cur->left != NULL)
        return maximum(cur->left);
    nodeptr tmp = cur->parent;
    while (tmp != NULL && tmp->left == cur)
        cur = tmp, tmp = tmp->parent;
    return tmp;
}
nodeptr find(nodeptr root, int key) {
    if (root == NULL)
        return NULL;
    if (key == root->key)
        return root;
    if (key < root->key)
        return find(root->left, key);
    return find(root->right, key);
}
nodeptr insert(nodeptr root, int key) {
    if (root == NULL)
        root = new node(key);
    else if (key < root->key) {
        root->left = insert(root->left, key);
        root->left->parent = root;
    }
    else if (key > root->key) {
        root->right = insert(root->right, key);
        root->right->parent = root;
    }
    return root;
}
nodeptr erase(nodeptr root, int key) {
    if (root == NULL)
        return root;
    if (key < root->key) {
        root->left = erase(root->left, key);
        root->left->parent = root;
    }
    else if (key > root->key) {
        root->right = erase(root->right, key);
        root->right->parent = root;
    }
    else {
        nodeptr tmp;
        if (root->left == NULL || root->right == NULL) {
            if (root->left == NULL)

```

```

        tmp = root->right;
    else
        tmp = root->left;
    free(root);
    return tmp;
}
else {
    tmp = successor(root);
    root->key = tmp->key;
    root->right = erase(root->right, tmp->key);
    root->right->parent = root;
}
}
return root;
}
};

public:
    nodeptr root;
    BST() :
        root(NULL) {
    }
    nodeptr find(int key) {
        return find(root, key);
    }
    void insert(int key) {
        root = insert(root, key);
    }
    void erase(int key) {
        root = erase(root, key);
    }
};

void inorder(nodeptr root) {
    if (root == NULL)
        return;
    inorder(root->left);
    cout << root->key << ' ';
    inorder(root->right);
}

void preorder(nodeptr root) {
    if (root == NULL)
        return;
    cout << root->key << ' ';
    preorder(root->left);
    preorder(root->right);
}

void postorder(nodeptr root) {
    if (root == NULL)
        return;
    postorder(root->left);
    postorder(root->right);
    cout << root->key << ' ';
}

```

AVL

```

struct AVLnode {
    int key, height;
    AVLnode* left, * right, * parent;
    static AVLnode* sentinel;
    AVLnode() {
        parent = left = right = sentinel;
        height = 0;
    }
}

```

```

AVLNode(int key) : key(key) {
    parent = left = right = sentinel;
    height = 0;
}

void updateHeight() {
    height = 1 + max(left->height, right->height);
}
int balanceFactor() {
    return left->height - right->height;
}
};

AVLNode* AVLNode::sentinel = new AVLNode();

class AVL : public BST {
    typedef AVLNode* nodeptr;
public:
    nodeptr root;
    AVL() : root(NULL) {}
    void insert(int key) { root = insert(root, key); }
private:
    nodeptr rightRotation(nodeptr Q) {
        nodeptr P = Q->left;
        Q->left = P->right;
        Q->left->parent = Q;
        P->right = Q;
        P->parent = Q->parent;
        Q->parent = P;
        Q->updateHeight();
        P->updateHeight();
        return P;
    }
    nodeptr leftRotation(nodeptr P) {
        nodeptr Q = P->right;
        P->right = Q->left;
        P->right->parent = P;
        Q->left = P;
        Q->parent = P->parent;
        P->parent = Q;
        Q->updateHeight();
        P->updateHeight();
        return Q;
    }
    nodeptr balance(nodeptr root) {
        if (root->balanceFactor() == 2) {
            if (root->left->balanceFactor() == -1)
                root->left = leftRotation(root->left);
            root = rightRotation(root);
        }
        else if (root->balanceFactor() == -2) {
            if (root->right->balanceFactor() == 1)
                root->right = rightRotation(root->right);
            root = leftRotation(root);
        }
        return root;
    }
    nodeptr insert(nodeptr root, int key) {
        if (root == AVLNode::sentinel)
            return root = new AVLNode(key);
        if (key < root->key) {
            root->left = insert(root->left, key);
            root->left->parent = root;
        }
    }
}

```

```

        else if (key > root->key) {
            root->right = insert(root->right, key);
            root->right->parent = root;
        }
        root->updateHeight();
        root = balance(root);
        return root;
    }
};

```

Heap

```

template<class T, class cmp = less<T>>
class heap {
    vector<T> v;
    void check() const {
        assert(size() > 0);
    }
    int parent(const int& node) const {
        return (node == 0 ? -1 : (node - 1) / 2);
    }
    int right(const int& node) const {
        int r = 2 * node + 2;
        return (r < size() ? r : -1);
    }
    int left(const int& node) const {
        int l = 2 * node + 1;
        return (l < size() ? l : -1);
    }
    void reheapUp(const int& node) {
        if (node == 0 || cmp()(v[parent(node)], v[node]))
            return;
        swap(v[node], v[parent(node)]);
        reheapUp(parent(node));
    }
    void reheapDown(const int& node) {
        int child = left(node);
        if (child == -1)
            return;
        int rightChild = right(node);
        if (rightChild != -1 && cmp()(v[rightChild], v[child]))
            child = rightChild;
        if (cmp()(v[node], v[child]))
            return;
        swap(v[node], v[child]);
        reheapDown(child);
    }
public:
    int size() const {
        return v.size();
    }
    void push(const int& val) {
        v.push_back(val);
        reheapUp((int)v.size() - 1);
    }
    const T& top() const {
        check();
        return v[0];
    }
    void pop() {
        check();
        v[0] = v.back();
        v.pop_back();
        reheapDown(0);
    }

```



```

    }
};

```

Big Integer

```

class BigInt {
private:
#define CUR (*this)
    const int BASE = 1000000000; // 1e9
    vector<int> v;
public:
    BigInt() {
    }
    BigInt(const long long &val) {
        CUR = val;
    }
    BigInt(const string &val) {
        CUR = val;
    }
    int size() const {
        return v.size();
    }
    bool zero() const {
        return v.empty();
    }
    BigInt& operator=(long long val) {
        v.clear();
        while (val) {
            v.push_back(val % BASE);
            val /= BASE;
        }
        return CUR;
    }
    BigInt& operator=(const BigInt &a) {
        v = a.v;
        return CUR;
    }
    BigInt& operator=(const string &s) {
        CUR = 0;
        for (const char &ch : s)
            CUR = CUR * 10 + (ch - '0');
        return CUR;
    }

    /*****compare*****/
    bool operator <(const BigInt &a) const {
        if (a.size() != size())
            return size() < a.size();
    }
}

```

```

    for (int i = size() - 1; i >= 0; i--) {
        if (v[i] != a.v[i])
            return v[i] < a.v[i];
    }
    return false;
}

bool operator >(const BigInt &a) const {
    return a < CUR;
}

bool operator ==(const BigInt &a) const {
    return !(CUR < a) && !(a < CUR);
}

bool operator <=(const BigInt &a) const {
    return ((CUR < a) || !(a < CUR));
}

/*****add*****/
BigInt operator +(const BigInt &a) const {
    BigInt res = CUR;
    int idx = 0, carry = 0;
    while (idx < a.size() || carry) {
        if (idx < a.size())
            carry += a.v[idx];
        if (idx == res.size())
            res.v.push_back(0);
        res.v[idx] += carry;
        carry = res.v[idx] / BASE;
        res.v[idx] %= BASE;
        idx++;
    }
    return res;
}

BigInt& operator +=(const BigInt &a) {
    CUR = CUR + a;
    return CUR;
}

/*****multiply*****/
BigInt operator *(const BigInt &a) const {
    BigInt res;
    if (CUR.zero() || a.zero())
        return res;
    res.v.resize(size() + a.size());
    for (int i = 0; i < size(); i++) {
        if (v[i] == 0)
            continue;
        long long carry = 0;
        for (int j = 0; carry || j < a.size(); j++) {
            carry += ILL * v[i] * (j < a.size() ? a.v[j] : 0);
            while (i + j >= res.size())
                res.v.push_back(0);
        }
    }
}

```

```

        carry += res.v[i + j];
        res.v[i + j] = carry % BASE;
        carry /= BASE;
    }
}
while (!res.v.empty() && res.v.back() == 0)
    res.v.pop_back();
return res;
}
BigInt& operator *=(const BigInt &a) {
    CUR = CUR * a;
    return CUR;
}
/*****Division*****/
BigInt& operator /=(const int &a) {
    ll carry = 0;
    for (int i = (int) v.size() - 1; i >= 0; i--) {
        ll cur = v[i] + carry * BASE;
        v[i] = cur / a;
        carry = cur % a;
    }
    while (!v.empty() && v.back() == 0)
        v.pop_back();
    return CUR;
}
/*****print*****/
friend ostream& operator<<(ostream &out, const BigInt &a) {
    out << (a.zero() ? 0 : a.v.back());
    for (int i = (int) a.v.size() - 2; i >= 0; i--)
        out << setfill('0') << setw(9) << a.v[i];
    return out;
}
#undef CUR
};

```

Graph

Graph Data structures

DSU

```

struct DSU {
    vector<int> rank, parent, size;
    vector<vector<int>> component;
    int forsets;
    DSU(int n) {
        size = rank = parent = vector<int>(n + 1, 1);
        component = vector<vector<int>>(n + 1);
        forsets = n;
        for (int i = 0; i <= n; i++) {
            parent[i] = i;
            component[i].push_back(i);
        }
    }
}

```

```

int find_set(int v) {
    if (v == parent[v])
        return v;
    return parent[v] = find_set(parent[v]);
}
void link(int par, int node) {
    parent[node] = par;
    size[par] += size[node];
    for (const int& it : component[node])
        component[par].push_back(it);
    component[node].clear();
    if (rank[par] == rank[node])
        rank[par]++;
    forsets--;
}
bool union_sets(int v, int u) {
    v = find_set(v), u = find_set(u);
    if (v != u) {
        if (rank[v] < rank[u])
            swap(v, u);
        link(v, u);
    }
    return v != u;
}
bool same_set(int v, int u) {
    return find_set(v) == find_set(u);
}
int size_set(int v) {
    return size[find_set(v)];
}
};

```

DSU apps

```

void Painting_subarrays() {
    struct Query {
        int l, r, c;
        Query(int l, int r, int c) :
            l(l), r(r), c(c) {}
    };
    int n, q;
    cin >> n >> q;
    DSU uf(n);
    vector<int> ans(n + 1);
    vector<Query> query(q);
    for (int i = 0; i < q; i++)
        cin >> query[i].l >> query[i].r >> query[i].c;
    reverse(query.begin(), query.end());
    for (auto q : query) {
        int l = q.l, r = q.r, c = q.c;
        for (int cur = uf.find_set(l); cur <= r; cur = uf.find_set(cur)) {
            uf.parent[cur] = cur + 1;
            ans[cur] = c;
        }
    }
}

void RMQ() {
    struct Query {
        int l, r, idx;
        Query(int l, int r, int idx) :
            l(l), r(r), idx(idx) {}
    };
};

```

```

int n, q;
cin >> n >> q;
vector<int> v(n);
vector < vector < Query >> query(n);
vector<int> ans(q);
DSU uf(n);
for (auto& a : v)
    cin >> a;
for (int i = 0; i < q; i++) {
    int l, r;
    cin >> l >> r;
    query[r].push_back(Query(l, r, i));
}
stack<int> st;
for (int i = 0; i < n; i++) {
    while (!st.empty() && v[st.top()] > v[i]) {
        uf.parent[st.top()] = i;
        st.pop();
    }
    st.push(i);
    for (auto q : query[i])
        ans[q.idx] = v[uf.find_set(q.l)];
}
}

```

DSU bipartiteness

```

struct DSU_bipartiteness {
    vector<int> bipartite, rank;
    vector<pair<int, int>> parent;
    DSU_bipartiteness(int n) {
        bipartite = rank = vector<int>(n + 1, 1);
        parent = vector<pair<int, int>>(n + 1);
        for (int i = 0; i <= n; i++)
            parent[i] = { i, 0 };
    }
    pair<int, int> find_set(int x) {
        if (x == parent[x].first)
            return parent[x];
        int parity = parent[x].second;
        parent[x] = find_set(parent[x].first);
        parent[x].second ^= parity;
        return parent[x];
    }
    void union_sets(int x, int y) {
        pair<int, int> p = find_set(x);
        x = p.first;
        int paX = p.second;
        p = find_set(y);
        y = p.first;
        int paY = p.second;
        if (x == y) {
            if (paX == paY)
                bipartite[x] = false;
        }
        else {
            if (rank[x] < rank[y])
                swap(x, y);
            parent[y] = { x, paX ^ paY ^ 1 };
            bipartite[x] &= bipartite[y];
            if (rank[x] == rank[y])
                rank[x]++;
        }
    }
}

```

```

        bool is_bipartite(int x) {
            return bipartite[find_set(x).first];
        }
};

```

LCA

```

class LCA {
    int n, logN, root = 1;
    vector<int> depth;
    vector<vector<int>>> adj, lca;
    void dfs(int node, int parent) {
        lca[node][0] = parent;
        depth[node] = (~parent ? depth[parent] + 1 : 0);
        for (int k = 1; k <= logN; k++) {
            int up_parent = lca[node][k - 1];
            if (~up_parent)
                lca[node][k] = lca[up_parent][k - 1];
        }
        for (int child : adj[node])
            if (child != parent)
                dfs(child, node);
    }
public:
    LCA(const vector<vector<int>>> &_adj, int root = 1) :
        root(root), adj(_adj) {
        adj = _adj;
        n = adj.size() - 1;
        logN = log2(n);
        lca = vector<vector<int>>>(n + 1, vector<int>(logN + 1, -1));
        depth = vector<int>(n + 1);
        dfs(root, -1);
    }
    int get_LCA(int x, int y) {
        if (depth[x] < depth[y])
            swap(x, y);
        for (int k = logN; k >= 0; k--)
            if (depth[x] - (1 << k) >= depth[y])
                x = lca[x][k];
        if (x == y)
            return x;
        for (int k = logN; k >= 0; k--) {
            if (lca[x][k] != lca[y][k]) {
                x = lca[x][k], y = lca[y][k];
            }
        }
        return lca[x][0];
    }
    int get_distance(int u, int v) {
        return depth[u] + depth[v] - 2 * depth[get_LCA(u, v)];
    }
    int shifting(int node, int dist) {
        for (int i = logN; i >= 0 && ~node; i--)

```

```

        if (dist & (1 << i))
            node = lca[node][i];
    return node;
}
edge get_path(int u, int LCA) {
    edge rt;
    for (int k = logN; k >= 0; k--)
        if (depth[u] - (1 << k) >= depth[LCA]) {
            rt = merge(rt, lca[u][k]);
            u = lca[u][k].to;
        }
    return rt;
}
};

```

Heavy light decomposition

```

class heavy_light_decomposition { //1-based,if value in node,just update it after build chains
    int n, is_value_in_edge;
    vector<int> parent, depth, heavy, root, pos_in_array, pos_to_node, size;
    const static int merge(int a, int b); //implement it
    struct array_ds { //implement it
        int n;
        array_ds(int n) :
            n(n) {
        }
        void update(int pos, int value);
        int query(int l, int r);
    } seg;
    struct TREE {
        int cnt_edges = 1;
        vector<vector<int>>> adj;
        //need for value in edges
        vector<vector<int>>> edge_idx;
        //edge_to need for undirected tree //end of edge in directed tree
        vector<int> edge_to, edge_cost;
        TREE(int n) :
            adj(n + 1), edge_idx(n + 1), edge_to(n + 1), edge_cost(n + 1) {
        }
        void add_edge(int u, int v, int c) {
            adj[u].push_back(v);
            adj[v].push_back(u);
            edge_idx[u].push_back(cnt_edges);
            edge_idx[v].push_back(cnt_edges);
            edge_cost[cnt_edges] = c;
            cnt_edges++;
        }
    } tree;
    int dfs_hld(int node) {
        int size = 1, max_sub_tree = 0;
        for (int i = 0; i < (int) tree.adj[node].size(); i++) {
            int ch = tree.adj[node][i], edge_idx = tree.edge_idx[node][i];
            if (ch != parent[node]) {

```

```

        tree.edge_to[edge_idx] = ch;
        parent[ch] = node;
        depth[ch] = depth[node] + 1;
        int child_size = dfs_hld(ch);
        if (child_size > max_sub_tree)
            heavy[node] = ch, max_sub_tree = child_size;
        size += child_size;
    }
}
return size;
}
vector<tuple<int, int, bool>> get_path(int u, int v) { //l,r,must_reverse?
    vector<pair<int, int>> tmp[2];
    bool idx = 1;
    while (root[u] != root[v]) {
        if (depth[root[u]] > depth[root[v]]) {
            swap(u, v);
            idx = !idx;
        }
        //if value in edges ,you need value of root[v] also (connector edge)
        tmp[idx].push_back( { pos_in_array[root[v]], pos_in_array[v] });
        v = parent[root[v]];
    }
    if (depth[u] > depth[v]) {
        swap(u, v);
        idx = !idx;
    }
    if (!is_value_in_edge || u != v)
        tmp[idx].push_back( { pos_in_array[u] + is_value_in_edge,
            pos_in_array[v] });
    reverse(all(tmp[1]));
    vector<tuple<int, int, bool>> rt;
    for (int i = 0; i < 2; i++)
        for (auto &it : tmp[i])
            rt.emplace_back(it.first, it.second, i == 0);
    return rt; //u is LCA
}
public:
heavy_light_decomposition(int n, bool is_value_in_edge) :
    n(n), is_value_in_edge(is_value_in_edge), seg(n + 1), tree(n + 1) {
    heavy = vector<int>(n + 1, -1);
    parent = depth = root = pos_in_array = pos_to_node = size = vector<int>(
        n + 1);
}
void add_edge(int u, int v, int c = 0) {
    tree.add_edge(u, v, c);
}
void build_chains(int src = 1) {
    parent[src] = -1;
    dfs_hld(src);
    for (int chain_root = 1, pos = 1; chain_root <= n; chain_root++) {
        if (parent[chain_root] == -1

```



```

        || heavy[parent[chain_root]] != chain_root)
    for (int j = chain_root; j != -1; j = heavy[j]) {
        root[j] = chain_root;
        pos_in_array[j] = pos++;
        pos_to_node[pos_in_array[j]] = j;
    }
}
if (is_value_in_edge)
    for (int i = 1; i < n; i++)
        update_edge(i, tree.edge_cost[i]);
}
void update_node(int node, int value) {
    seg.update(pos_in_array[node], value);
}
void update_edge(int edge_idx, int value) {
    update_node(tree.edge_to[edge_idx], value);
}
void update_path(int u, int v, ll c) {
    vector<tuple<int, int, bool>> intervals = get_path(u, v);
    for (auto &it : intervals)
        seg.update(get<0>(it), get<1>(it), c);
}
node query_in_path(int u, int v) {
    vector<tuple<int, int, bool>> intervals = get_path(u, v);
    //initial value, check if handling u == v
    node query_res = 0;
    for (auto &it : intervals) {
        int l, r;
        bool rev;
        tie(l, r, rev) = it;
        node cur = seg.query(l, r);
        if (rev)
            cur.reverse();
        query_res = node(query_res, cur);
    }
    return query_res;
}
};

```

centroid decomposition

```

class centroid_decomposition {
    vector<bool> centroidMarked;
    vector<int> size;
    void dfsSize(int node, int par) {
        size[node] = 1;
        for (int ch : adj[node])
            if (ch != par && !centroidMarked[ch]) {
                dfsSize(ch, node);
                size[node] += size[ch];
            }
    }
    int getCenter(int node, int par, int size_of_tree) {

```

```

bool is_centroid = true;
int heaviest_child = -1;
for (int ch : adj[node])
    if (ch != par && !centroidMarked[ch]) {
        if (size[ch] > size_of_tree / 2)
            is_centroid = false;
        if (heaviest_child == -1 || size[ch] > size[heaviest_child])
            heaviest_child = ch;
    }
if (is_centroid && size_of_tree - size[node] <= size_of_tree / 2)
    return node;
assert(heaviest_child != -1);
return getCenter(heaviest_child, node, size_of_tree);
}

int getCentroid(int src) {
    dfsSize(src, -1);
    int centroid = getCenter(src, -1, size[src]);
    centroidMarked[centroid] = true; //need to mark it after solve?
    return centroid;
}

int decomposeTree(int root) {
    root = getCentroid(root);
    solve(root);
    for (int ch : adj[root]) {
        if (centroidMarked[ch])
            continue;
        int centroid_of_subtree = decomposeTree(ch);
        //note: root and centroid_of_subtree probably not have a direct edge in adj
        centroidTree[root].push_back(centroid_of_subtree);
        centroidParent[centroid_of_subtree] = root;
    }
    return root;
}

void calc(int node, int par) {
    //TO-DO
    for (int ch : adj[node])
        if (ch != par && !centroidMarked[ch])
            calc(ch, node);
}

void add(int node, int par) {
    //TO-DO
    for (int ch : adj[node])
        if (ch != par && !centroidMarked[ch])
            add(ch, node);
}

void remove(int node, int par) {
    //TO-DO
    for (int ch : adj[node])
        if (ch != par && !centroidMarked[ch])
            remove(ch, node);
}

void solve(int root) {

```

```

//add root
for (int ch : adj[root])
    if (!centroidMarked[ch]) {
        calc(ch, root);
        add(ch, root);
    }
//remove root
for (int ch : adj[root])
    if (!centroidMarked[ch])
        remove(ch, root);
}
public:
    int n, root;
    vector<vector<int>> adj, centroidTree;
    vector<int> centroidParent;
    centroid_decomposition(vector<vector<int>> &adj) :
        adj(adj) {
        n = (int) adj.size() - 1;
        size = vector<int>(n + 1);
        centroidTree = vector<vector<int>>(n + 1);
        centroidParent = vector<int>(n + 1, -1);
        centroidMarked = vector<bool>(n + 1);
        root = decomposeTree(1);
    }
};

```

shortest path algorithms

Dijkstra

```

struct edge {
    int from, to, weight;
    edge() {
        from = to = weight = 0;
    }
    edge(int from, int to, int weight) :
        from(from), to(to), weight(weight) {
    }
    bool operator <(const edge& other) const {
        return weight > other.weight;
    }
};
vector<vector<edge>> adj;

//O(E*log(v))
void dijkstra(int src, int dest = -1) {
    priority_queue<edge> q;
    vector<int> dis(adj.size(), INT_MAX), prev(adj.size(), -1);
    q.push(edge(-1, src, 0));
    dis[src] = 0;
    while (!q.empty()) {
        edge e = q.top();
        q.pop();
        if (e.weight > dis[e.to])
            continue;
        prev[e.to] = e.from;
        if (e.to == dest)
            break;
    }
}

```

```

        for (edge ne : adj[e.to])
            if (dis[ne.to] > dis[e.to] + ne.weight) {
                ne.weight = dis[e.to] + ne.weight;
                q.push(ne);
            }
    }
    vector<int> path;
    while (dest != -1) {
        path.push_back(dest);
        dest = prev[dest];
    }
    reverse(path.begin(), path.end());
}

```

Bellmanford

```

vector<edge> edgeList;
//O(V*E)
void bellmanford(int n, int src, int dest = -1) {
    vector<int> dis(n + 1, oo), prev(n + 1, -1);
    dis[src] = 0;
    bool negativeCycle = false;
    int last = -1, tmp = n;
    while (tmp--) {
        last = -1;
        for (edge e : edgeList)
            if (dis[e.to] > dis[e.from] + e.weight) {
                dis[e.to] = dis[e.from] + e.weight;
                prev[e.to] = e.from;
                last = e.to;
            }
        if (last == -1)
            break;
        if (tmp == 0)
            negativeCycle = true;
    }
    if (last != -1) {
        for (int i = 0; i < n; i++)
            last = prev[last];
        vector<int> cycle;
        for (int cur = last; cur != last || cycle.size() > 1; cur = prev[cur])
            cycle.push_back(cur);
        reverse(cycle.begin(), cycle.end());
    }
    vector<int> path;
    while (dest != -1) {
        path.push_back(dest);
        dest = prev[dest];
    }
    reverse(path.begin(), path.end());
}

```

Difference constraints

```

void difference_constraints() {
    int m;
    cin >> m;
    int cnt = 1;
    while (m--) {
        string x1, x2;
        int w; // x1 - x2 <= w
        cin >> x1 >> x2 >> w;
        map<string, int> id;
        if (id.find(x1) == id.end())
            id[x1] = cnt++;
    }
}

```

```

        if (id.find(x2) == id.end())
            id[x2] = cnt++;
        edgeList.emplace_back(id[x2], id[x1], w);
    }
    for (int i = 1; i < cnt; i++)
        edgeList.emplace_back(cnt, i, 0);
    bellmanford(cnt, cnt);
}

```

Floyed

```

vector<vector<int>> adj, par;
// adj[i][j] = oo , adj[i][i] = 0 , par[i][j] = i
void init(int n) {
    par = adj = vector<vector<int>>(n + 1, vector<int>(n + 1, oo));
    for (int i = 1; i <= n; i++)
        adj[i][i] = 0;
    for (int i = 1; i <= n; i++)
        for (int j = 1; j <= n; j++)
            par[i][j] = i;
}
void floyd() {
    for (int k = 1; k < adj.size(); k++)
        for (int i = 1; i < adj.size(); i++)
            for (int j = 1; j < adj.size(); j++)
                if (adj[i][j] > adj[i][k] + adj[k][j]) {
                    adj[i][j] = adj[i][k] + adj[k][j];
                    par[i][j] = par[k][j];
                }
}
void buildPath(int src, int dest) {
    vector<int> path;
    while (src != dest) {
        path.push_back(dest);
        dest = par[src][dest];
    }
    path.push_back(src);
    reverse(path.begin(), path.end());
}

```

SPFA

```

vector<vector<edge>> adj;
void spfa(int src) {
    enum visit {
        finished, in_queue, not_visited
    };
    int n = adj.size();
    vector<int> dis(n, INF), prev(n, -1), state(n, not_visited);
    dis[src] = 0;
    deque<int> q;
    q.push_back(src);
    while (!q.empty()) {
        int u = q.front();
        q.pop_front();
        state[u] = finished;
        for (auto &e : adj[u]) {
            if (dis[e.to] > dis[e.from] + e.cost) {
                dis[e.to] = dis[e.from] + e.cost;
                prev[e.to] = e.from;
                if (state[e.to] == not_visited)

```

```

        q.push_back(e.to);
    else if (state[e.to] == finished)
        q.push_front(e.to);
    state[e.to] = in_queue;
}
}
}
}
}

```

MST

Kruskal

```

struct edge {
    int from, to;
    ll weight;
    edge() {
        from = to = weight = 0;
    }
    edge(int from, int to, ll weight) :
        from(from), to(to), weight(weight) {
    }
    bool operator <(const edge& other) const {
        return weight < other.weight;
    }
};

vector<edge> edgeList;
pair<int, vector<edge>> MST_Kruskal(int n) { //O(edges*log(edges))
    DSU uf(n);
    vector< edge > edges;
    int mstCost = 0;
    sort(edgeList.begin(), edgeList.end());
    for (auto e : edgeList)
        if (uf.union_sets(e.from, e.to)) {
            mstCost += e.weight;
            edges.push_back(e);
        }
    if (edges.size() != n - 1)
        return { INT_MAX, vector<edge>() };
    return { mstCost, edges };
}

int miniMax(int src, int dest, int n) {
    int max = INT_MIN;
    DSU uf(n);
    sort(edgeList.begin(), edgeList.end());
    for (auto e : edgeList) {
        if (uf.same_set(src, dest))
            return max;
        uf.union_sets(e.from, e.to);
        max = e.weight;
    }
    return max;
}

//O(edges*log(edges) + nodes*nodes)
pair<int, vector<edge>> SMST_Kruskal(int n) {
    DSU uf(n);
    sort(edgeList.begin(), edgeList.end());
    vector<edge> take, leave;
    int mstCost = 0;
    for (auto e : edgeList)
        if (uf.union_sets(e.from, e.to)) {

```

```

        mstCost += e.weight;
        take.push_back(e);
    }
    else leave.push_back(e);
pair<int, vector<edge>> ret = { INT_MAX, vector<edge>() };
for (int i = 0; i < take.size(); i++) {
    uf = DSU(n);
    vector < edge > edges;
    mstCost = 0;
    for (int j = 0; j < take.size(); j++) {
        if (i == j)
            continue;
        uf.union_sets(take[j].from, take[j].to);
        mstCost += take[j].weight;
        edges.push_back(take[j]);
    }
    for (edge e : leave) {
        if (uf.union_sets(e.from, e.to)) {
            mstCost += e.weight;
            edges.push_back(e);
            break;
        }
    }
    if (edges.size() == n - 1 && ret.first < mstCost)
        ret = { mstCost, edges };
}
return ret;
}

```

Prim

```

struct edge {
    int from, to, weight;
    edge() {
        from = to = weight = 0;
    }
    edge(int from, int to, int weight) :
        from(from), to(to), weight(weight) {
    }
    bool operator <(const edge& other) const {
        return weight > other.weight;
    }
};

```

```

vector<vector<edge>> adj;
vector<edge> prim(int node) {
    vector<bool> vis(adj.size());
    priority_queue<edge> q;
    vector<edge> edges;
    q.push(edge(-1, node, 0));
    while (!q.empty()) {
        edge e = q.top();
        q.pop();
        if (vis[e.to])
            continue;
        vis[e.to] = true;
        if (e.from != -1)
            edges.push_back(e);
        for (edge ch : adj[e.to])
            if (!vis[ch.to])
                q.push(ch);
    }
    return edges; //check it connected or not
}

```

SMST

```
struct edge {
    int from, to;
    ll weight;
    edge() {
        from = to = weight = 0;
    }
    edge(int from, int to, ll weight) :
        from(from), to(to), weight(weight) {
    }
    bool operator <(const edge& other) const {
        return weight < other.weight;
    }
};

int MST_Kruskal(int n, vector<edge> edgeList, vector<edge>& take,
vector<edge>& leave) {
    DSU uf(n);
    vector<edge> edges;
    sort(edgeList.begin(), edgeList.end());
    int mst_cost = 0;
    for (auto e : edgeList)
        if (uf.union_sets(e.from, e.to)) {
            take.push_back(e);
            mst_cost += e.weight;
        }
        else leave.push_back(e);
    return mst_cost;
}

struct LCA {
#define INIT { -1, -2 }
    struct data {
        int lca = -1;
        pair<int, int> max_edges = INIT; //first max,second max (distinct)
    };
    pair<int, int> merge(pair<int, int> a, pair<int, int> b) {
        if (a.first < b.first)
            swap(a, b);
        if (b.first == a.first)
            a.second = max(a.second, b.second);
        else if (b.first > a.second)
            a.second = b.first;
        return a;
    }
    int logN;
    vector<vector<data>> lca;
    vector<vector<edge>> adj;
    vector<int> depth;
    void dfs(int node, int par) {
        for (edge e : adj[node])
            if (e.to != par) {
                depth[e.to] = depth[node] + 1;
                lca[e.to][0].max_edges.first = e.weight;
                lca[e.to][0].lca = node;
                dfs(e.to, node);
            }
    }
    LCA(int n, vector<edge>& edges) :
        adj(n + 1) {
            for (auto& e : edges) {
```



```

        adj[e.from].push_back(e);
        adj[e.to].push_back(edge(e.to, e.from, e.weight));
    }
    logN = log2(n);
    depth = vector<int>(n + 1);
    lca = vector<vector<data>>(n + 1, vector<data>(logN + 1));
    dfs(1, -1);
    for (int k = 1; k <= logN; k++)
        for (int node = 1; node <= n; node++) {
            int par = lca[node][k - 1].lca;
            if (~par) {
                lca[node][k].lca = lca[par][k - 1].lca;
                lca[node][k].max_edges = merge(lca[node][k - 1].max_edges,
                                                lca[par][k - 1].max_edges);
            }
        }
}

pair<int, int> max_two_edges(int u, int v) {
    pair<int, int> ans = INIT;
    if (depth[u] < depth[v])
        swap(u, v);
    for (int i = logN; i >= 0; i--)
        if (depth[u] - (1 << i) >= depth[v]) {
            ans = merge(ans, lca[u][i].max_edges);
            u = lca[u][i].lca;
        }
    if (u == v)
        return ans;
    for (int i = logN; i >= 0; i--)
        if (lca[u][i].lca != lca[v][i].lca) {
            ans = merge(ans, lca[u][i].max_edges);
            ans = merge(ans, lca[v][i].max_edges);
            u = lca[u][i].lca;
            v = lca[v][i].lca;
        }
    ans = merge(ans, lca[u][0].max_edges);
    ans = merge(ans, lca[v][0].max_edges);
    return ans;
}

};

int main() {
    run();
    int t;
    cin >> t;
    for (int I = 1; I <= t; I++) {
        int n, e;
        cin >> n >> e;
        vector<edge> edgeList(e);
        for (auto& it : edgeList)
            cin >> it.from >> it.to >> it.weight;
        vector<edge> take, leave;
        int mst_cost = MST_Kruskal(n, edgeList, take, leave);
        if (take.size() != n - 1) {
            cout << "No way\n";
            continue;
        }
        LCA tree(n, take);
        ll rt = INF;
        for (edge e : leave) {
            pair<int, int> p = tree.max_two_edges(e.from, e.to);
            rt = min(rt, mst_cost - p.first + e.weight);
        }
        if (rt == INF)
            cout << "No second way\n";
    }
}

```

```

        else
            cout << rt << endl;
    }
}

```

Tarjan

SCC

```

vector<vector<int>> adj, scc;
vector<set<int>> dag;
vector<int> dfs_num, dfs_low, compId;
vector<bool> inStack;
stack<int> stk;
int timer;

void dfs(int node) {
    dfs_num[node] = dfs_low[node] = ++timer;
    stk.push(node);
    inStack[node] = 1;
    for (int child : adj[node])
        if (!dfs_num[child]) {
            dfs(child);
            dfs_low[node] = min(dfs_low[node], dfs_low[child]);
        }
        else if (inStack[child])
            dfs_low[node] = min(dfs_low[node], dfs_num[child]);
    //can be dfs_low[node] = min(dfs_low[node], dfs_low[child]);
    if (dfs_low[node] == dfs_num[node]) {
        scc.push_back(vector<int>());
        int v = -1;
        while (v != node) {
            v = stk.top();
            stk.pop();
            inStack[v] = 0;
            scc.back().push_back(v);
            compId[v] = scc.size() - 1;
        }
    }
}

void SCC() {
    timer = 0;
    dfs_num = dfs_low = compId = vector<int>(adj.size());
    inStack = vector<bool>(adj.size());
    scc = vector<vector<int>>();
    for (int i = 1; i < adj.size(); i++)
        if (!dfs_num[i])
            dfs(i);
}

void DAG() {
    dag = vector<set<int>>(scc.size());
    for (int i = 1; i < adj.size(); i++)
        for (int j : adj[i])
            if (compId[i] != compId[j])
                dag[compId[i]].insert(compId[j]);
}

```

Articulation points and bridges

```

vector<vector<int>> adj;
vector<int> dfs_num, dfs_low;

```

```

vector<bool> articulation_point;
vector<pair<int, int>> bridge;
stack<pair<int, int>> edges;
vector<vector<pair<int, int>>> BCC; //biconnected components
int timer, cntChild;

void dfs(int node, int par) {
    dfs_num[node] = dfs_low[node] = ++timer;
    for (int child : adj[node]) {
        if (par != child && dfs_num[child] < dfs_num[node])
            edges.push({ node, child });

        if (!dfs_num[child]) {
            if (par == -1)
                cntChild++;
            dfs(child, node);
            if (dfs_low[child] >= dfs_num[node]) {
                articulation_point[node] = 1;
                //get biconnected component
                BCC.push_back(vector<pair<int, int>>());
                pair<int, int> edge;
                do {
                    edge = edges.top();
                    BCC.back().push_back(edge);
                    edges.pop();
                } while (edge.first != node || edge.second != child);
            }
            if (dfs_low[child] > dfs_num[node]) //can be (dfs_low[child] == dfs_num[child])
                bridge.push_back({ node, child });
            dfs_low[node] = min(dfs_low[node], dfs_low[child]);
        }
        else if (child != par)
            dfs_low[node] = min(dfs_low[node], dfs_num[child]);
    }
}

void articulation_points_and_bridges() {
    timer = 0;
    dfs_num = dfs_low = vector<int>(adj.size());
    articulation_point = vector<bool>(adj.size());
    bridge = vector<pair<int, int>>();
    for (int i = 1; i < adj.size(); i++)
        if (!dfs_num[i]) {
            cntChild = 0;
            dfs(i, -1);
            articulation_point[i] = cntChild > 1;
        }
}

```

Edge classification

```

vector<vector<int>> adj;
vector<int> start, finish;
int timer;
void dfsEdgeClassification(int node) {
    start[node] = timer++;
    for (int child : adj[node]) {
        if (start[child] == -1)
            dfsEdgeClassification(child);
        else {
            if (finish[child] == -1)
                ; // Back Edge
            else if (start[node] < start[child])
                ; // Forward Edge
        }
    }
}

```

```

        else; // Cross Edge
    }
}
finish[node] = timer++;
}

```

2-SAT

```

#include "..\strongly_connected_component.h"
int n;
int Not(int x) {
    return (x > n ? x - n : x + n);
}

void addEdge(int a, int b) {
    adj[Not(a)].push_back(b);
    adj[Not(b)].push_back(a);
}

void add_xor_edge(int a, int b) {
    addEdge(Not(a), Not(b));
    addEdge(a, b);
}

bool _2SAT(vector<int>& value) {
    SCC();
    for (int i = 1; i <= n; i++)
        if (compId[i] == compId[Not(i)])
            return false;
    vector<int> assign(scc.size(), -1);
    for (int i = 0; i < scc.size(); i++)
        if (assign[i] == -1) {
            assign[i] = true;
            assign[compId[Not(scc[i].back())]] = false;
        }
    for (int i = 1; i <= n; i++)
        value[i] = assign[compId[i]];
    return true;
}

```

Flows

Maximum bipartite matching

```

vector<vector<int>> adj;
vector<int> rowAssign, colAssign, vis;
int test_id;
bool canMatch(int i) {
    for (int j : adj[i]) {
        if (vis[j] == test_id)
            continue;
        vis[j] = test_id;
        if (colAssign[j] == -1 || canMatch(colAssign[j])) {
            colAssign[j] = i;
            rowAssign[i] = j;
            return true;
        }
    }
    return false;
}

// O(rows * edges) //number of operation could be strictly less than order (1e5*1e5->AC)
int maximum_bipartite_matching(int rows, int cols) {
    int maxFlow = 0;
    rowAssign = vector<int>(rows, -1);

```

```

colAssign = vector<int>(cols, -1);
vis = vector<int>(cols);
for (int i = 0; i < rows; i++) {
    test_id++;
    if (canMatch(i))
        maxFlow++;
}
vector<pair<int, int>> matches;
for (int j = 0; j < cols; j++)
    if (~colAssign[j])
        matches.push_back({ colAssign[j], j });
return maxFlow;
}

```

Edmonds Karp

//O(V * E * E)

```

#define INF 0x3f3f3f3f3f3f3fLL
int n;
int capacity[101][101];
int getPath(int src, int dest, vector<int> &parent) {
    parent = vector<int>(n + 1, -1);
    queue<pair<int, int>> q;
    q.push( { src, INF } );
    while (q.size()) {
        int cur = q.front().first, flow = q.front().second;
        q.pop();
        if (cur == dest)
            return flow;
        for (int i = 1; i <= n; i++)
            if (parent[i] == -1 && capacity[cur][i]) {
                parent[i] = cur;
                q.push( { i, min(flow, capacity[cur][i]) } );
                if (i == dest) return q.back().second;
            }
    }
    return 0;
}
int Edmonds_Karp(int source, int sink) {
    int max_flow = 0;
    int new_flow = 0;
    vector<int> parent(n + 1, -1);
    while (new_flow = getPath(source, sink, parent)) {
        max_flow += new_flow;
        int cur = sink;
        while (cur != source) {
            int prev = parent[cur];
            capacity[prev][cur] -= new_flow;
            capacity[cur][prev] += new_flow;
            cur = prev;
        };
    }
    return max_flow;
}

```

Dinic

// $O(V \cdot V \cdot E)$ more faster

```
struct Dinic { //0-based
    struct flowEdge {
        int from, to;
        ll cap, flow = 0;
        flowEdge(int from, int to, ll cap) :
            from(from), to(to), cap(cap) {
        }
    };
    vector<flowEdge> edges;
    int n, m = 0, source, sink;
    vector<vector<int>>> adj;
    vector<int> level, ptr;
    Dinic(int n, int source, int sink) :
        n(n), source(source), sink(sink), adj(n), level(n), ptr(n) {
    }
    void addEdge(int u, int v, ll cap) {
        edges.emplace_back(u, v, cap);
        edges.emplace_back(v, u, 0);
        adj[u].push_back(m);
        adj[v].push_back(m + 1);
        m += 2;
    }
    bool bfs() {
        queue<int> q;
        level = vector<int>(n, -1);
        level[source] = 0;
        q.push(source);
        while (!q.empty()) {
            int cur = q.front();
            q.pop();
            for (auto &id : adj[cur]) {
                if (edges[id].cap - edges[id].flow <= 0)
                    continue;
                int nxt = edges[id].to;
                if (level[nxt] != -1)
                    continue;
                level[nxt] = level[cur] + 1;
                q.push(nxt);
            }
        }
        return level[sink] != -1;
    }
    ll dfs(int node, ll cur_flow) {
        if (cur_flow == 0 || node == sink)
```

```

    return cur_flow;
for (int &cid = ptr[node]; cid < adj[node].size(); cid++) {
    int id = adj[node][cid];
    int nxt = edges[id].to;
    if (level[node] + 1 != level[nxt]
        || edges[id].cap - edges[id].flow <= 0)
        continue;
    ll tmp = dfs(nxt, min(cur_flow, edges[id].cap - edges[id].flow));
    if (tmp == 0)
        continue;
    edges[id].flow += tmp;
    edges[id ^ 1].flow -= tmp;
    return tmp;
}
return 0;
}
ll flow() {
    ll max_flow = 0;
    while (bfs()) {
        fill(ptr.begin(), ptr.end(), 0);
        while (ll pushed = dfs(source, INF))
            max_flow += pushed;
    }
    return max_flow;
}
};

```

Min cost Max flow

```

struct MCMF { //0-based
    struct edge {
        int from, to, cost, cap, flow, backEdge;
        edge() {
            from = to = cost = cap = flow = backEdge = 0;
        }
        edge(int from, int to, int cost, int cap, int flow, int backEdge) :
            from(from), to(to), cost(cost), cap(cap), flow(flow), backEdge(
                backEdge) {
        }
        bool operator <(const edge &other) const {
            return cost < other.cost;
        }
    };
    int n, src, dest;
    vector<vector<edge>> adj;
    const int OO = 1e9;
    MCMF(int n, int src, int dest) :
        n(n), src(src), dest(dest), adj(n) {
    }
    void addEdge(int u, int v, int cost, int cap) {
        edge e1 = edge(u, v, cost, cap, 0, adj[v].size());
        edge e2 = edge(v, u, -cost, 0, 0, adj[u].size());
    }
};

```

```

    adj[u].push_back(e1);
    adj[v].push_back(e2);
}
pair<int, int> minCostMaxFlow() {
    int maxFlow = 0, cost = 0;
    while (true) {
        vector<pair<int, int>> path = spfa();
        if (path.empty())
            break;
        int new_flow = OO;
        for (auto &it : path) {
            edge &e = adj[it.first][it.second];
            new_flow = min(new_flow, e.cap - e.flow);
        }
        for (auto &it : path) {
            edge &e = adj[it.first][it.second];
            e.flow += new_flow;
            cost += new_flow * e.cost;
            adj[e.to][e.backEdge].flow -= new_flow;
        }
        maxFlow += new_flow;
    }
    return {maxFlow, cost};
}
enum visit {
    finished, in_queue, not_visited
};
vector<pair<int, int>> spfa() {
    vector<int> dis(n, OO), prev(n, -1), from_edge(n), state(n,
        not_visited);
    deque<int> q;
    dis[src] = 0;
    q.push_back(src);
    while (!q.empty()) {
        int u = q.front();
        q.pop_front();
        state[u] = finished;
        for (int i = 0; i < adj[u].size(); i++) {
            edge e = adj[u][i];
            if (e.flow >= e.cap || dis[e.to] <= dis[u] + e.cost)
                continue;
            dis[e.to] = dis[u] + e.cost;
            prev[e.to] = u;
            from_edge[e.to] = i;
            if (state[e.to] == in_queue)
                continue;
            if (state[e.to] == finished
                || (!q.empty() && dis[q.front()] > dis[e.to]))
                q.push_front(e.to);
            else
                q.push_back(e.to);
            state[e.to] = in_queue;
        }
    }
}

```



```

    }
}

if (dis[dest] == OO)
    return {};
vector<pair<int, int>> path;
int cur = dest;
while (cur != src) {
    path.push_back( { prev[cur], from_edge[cur] });
    cur = prev[cur];
}
reverse(path.begin(), path.end());
return path;
}
};

```

String

Hashing

```

struct hashing {
    int MOD, BASE;
    vector<int> Hash, modInv;
    hashing(string s, int MOD, int BASE, char first_char = 'a') :
        MOD(MOD), BASE(BASE), Hash(sz(s) + 1), modInv(sz(s) + 1) {
        modInv[0] = 1;
        ll base = 1;
        for (int i = 1; i <= sz(s); i++) {
            Hash[i] = (Hash[i - 1] + (s[i - 1] - first_char + 1) * base) % MOD;
            modInv[i] = power(base, MOD - 2, MOD);
            base = (base * BASE) % MOD;
        }
    }
    int getHash(int l, int r) { //1-based
        return ((Hash[r] - Hash[l - 1] + MOD) % MOD * modInv[l]) % MOD;
    }
};

//MOD = 1e9 + 9 ,BASE = 31
//MOD = 2000000011 ,BASE = 53 ->careful of overflow
//*****
//MOD = 998634293,BASE = 953
//MOD = 986464091,BASE = 1013

```

KMP

```

string pattern;
vector<int> longestPrefix;
int fail(int k, char nxt) {
    while (k > 0 && pattern[k] != nxt)
        k = longestPrefix[k - 1];
    if (nxt == pattern[k])
        k++;
    return k;
}
void failure_function() {
    int n = pattern.size();
    longestPrefix = vector<int>(n);
    for (int i = 1, k = 0; i < n; i++)
        longestPrefix[i] = k = fail(k, pattern[i]);
}

```

```

void KMP(const string& str) {
    int n = str.size();
    int m = pattern.size();
    for (int i = 0, k = 0; i < n; i++) {
        k = fail(k, str[i]);
        if (k == m) {
            cout << i - m + 1 << endl; //0-based
            k = longestPrefix[k - 1]; // if you want next match
        }
    }
}

```

Trie tree

```

class trie {
    struct trie_node {
        bool is_leaf = false;
        map<char, int> next;
        bool have_next(char ch) {
            return next.find(ch) != next.end();
        }
        int& operator[](char ch) {
            return next[ch];
        }
    };
    vector<trie_node> t;
public:
    trie() {
        t.push_back(trie_node());
    }
    void insert(const string &s) {
        int root = 0;
        for (const char &ch : s) {
            if (!t[root].have_next(ch)) {
                t.push_back(trie_node());
                t[root][ch] = t.size() - 1;
                //t[root][ch] = add_node();doesn't work if next is array
            }
            root = t[root][ch];
        }
        t[root].is_leaf = true;
    }
    bool find(const string &s) {
        int root = 0;
        for (const char &ch : s) {
            if (!t[root].have_next(ch))
                return false;
            root = t[root][ch];
        }
        return t[root].is_leaf;
    }
};

```

Aho Corasick

```
struct aho_corasick {
    struct trie_node {
        vector<int> pIdxs; //probably take memory limit
        map<char, int> next;
        int fail;
        trie_node() :
            fail(-1) {
        }
        bool have_next(char ch) {
            return next.find(ch) != next.end();
        }
        int& operator[](char ch) {
            return next[ch];
        }
    };
    vector<trie_node> t;
    vector<string> patterns;
    vector<int> end_of_pattern;
    vector<vector<int>> adj;
    int insert(const string &s, int patternIdx) {
        int root = 0;
        for (const char &ch : s) {
            if (!t[root].have_next(ch)) {
                t.push_back(trie_node());
                t[root][ch] = t.size() - 1;
            }
            root = t[root][ch];
        }
        t[root].pIdxs.push_back(patternIdx);
        return root;
    }
    int next_state(int cur, char ch) {
        while (cur > 0 && !t[cur].have_next(ch))
            cur = t[cur].fail;
        if (t[cur].have_next(ch))
            return t[cur][ch];
        return 0;
    }
    void buildAhoTree() {
        queue<int> q;
        for (auto &child : t[0].next) {
            q.push(child.second);
            t[child.second].fail = 0;
        }
        while (!q.empty()) {
            int cur = q.front();
            q.pop();
            for (auto &child : t[cur].next) {
                int k = next_state(t[cur].fail, child.first);
                t[child.second].fail = k;
            }
        }
    }
};
```

```

        vector<int> &idxs = t[child.second].pIdxs;
        //dp[child.second] = max(dp[child.second],dp[k]);
        idxs.insert(idxs.end(), all(t[k].pIdxs));
        q.push(child.second);
    }
}
}
void buildFailureTree() {
    adj = vector<vector<int>>(t.size());
    for (int i = 1; i < t.size(); i++)
        adj[t[i].fail].push_back(i);
}
aho_corasick(const vector<string> &_patterns) {
    t.push_back(trie_node());
    patterns = _patterns;
    end_of_pattern = vector<int>(patterns.size());
    for (int i = 0; i < patterns.size(); i++)
        end_of_pattern[i] = insert(patterns[i], i);
    buildAhoTree();
    buildFailureTree();
}
vector<vector<int>> match(const string &str) {
    int k = 0;
    vector<vector<int>> rt(patterns.size());
    for (int i = 0; i < str.size(); i++) {
        k = next_state(k, str[i]);
        for (auto &it : t[k].pIdxs)
            rt[it].push_back(i);
    }
    return rt;
}
};

```

Suffix Automaton

```

struct suffix_automaton {
    struct state {
        int len, link = 0, cnt = 0;
        bool terminal = false, is_clone = false;
        map<char, int> next;
        state(int len = 0) :
            len(len) {
        }
        bool have_next(char ch) {
            return next.find(ch) != next.end();
        }
        void clone(const state &other, int nlen) {
            len = nlen;
            next = other.next;
            link = other.link;
            is_clone = true;
        }
    };
};

```

```

vector<state> st;
int last = 0;
suffix_automaton() {
    st.push_back(state());
    st[0].link = -1;
}
suffix_automaton(const string &s) :
    suffix_automaton() {
    for (char ch : s)
        extend(ch);
    mark_terminals();
}
void mark_terminals() {
    for (int cur = last; cur > 0; cur = st[cur].link)
        st[cur].terminal = true;
}
void extend(char c) {
    int cur = st.size();
    st.push_back(state(st[last].len + 1));
    st[cur].cnt = 1;
    int p = last;
    last = cur;
    while (p != -1 && !st[p].have_next(c)) {
        st[p].next[c] = cur;
        p = st[p].link;
    }
    if (p == -1)
        return;
    int q = st[p].next[c];
    if (st[p].len + 1 == st[q].len) {
        st[cur].link = q;
        return;
    }
    int clone = st.size();
    st.push_back(state());
    st[clone].clone(st[q], st[p].len + 1);
    while (p != -1 && st[p].next[c] == q) {
        st[p].next[c] = clone;
        p = st[p].link;
    }
    st[q].link = st[cur].link = clone;
}
void calc_number_of_occurrences() {
    vector<vector<int>> lvl(st[last].len + 1);
    for (int i = 1; i < st.size(); i++)
        lvl[st[i].len].push_back(i);
    for (int i = st[last].len; i >= 0; i--)
        for (auto cur : lvl[i])
            st[st[cur].link].cnt += st[cur].cnt;
}

vector<ll> dp;

```

```

ll Count(int cur) { //count number of paths
    ll &rt = dp[cur];
    if (rt)
        return rt;
    rt = 1;
    for (auto ch : st[cur].next)
        rt += Count(ch.second);
    return rt;
}

string kth_substring(ll k) { //1-based,different substring,0 = ""
    assert(k <= Count(0));
    string rt;
    int cur = 0;
    while (k > 0) {
        for (auto ch : st[cur].next) {
            if (Count(ch.second) < k)
                k -= Count(ch.second);
            else {
                rt += ch.first;
                cur = ch.second;
                k--;
                break;
            }
        }
    }
    return rt;
}

string longest_common_substring(const string &t) {
    int cur = 0, l = 0, mx = 0, idx = 0;
    for (int i = 0; i < t.size(); i++) {
        while (cur > 0 && !st[cur].have_next(t[i])) {
            cur = st[cur].link;
            l = st[cur].len;
        }
        if (st[cur].have_next(t[i])) {
            cur = st[cur].next[t[i]];
            l++;
        }
        if (l > mx) {
            mx = l;
            idx = i;
        }
    }
    return t.substr(idx - mx + 1, mx);
}
};

```

Suffix array

```
class suffix_array {
    int getOrder(int a) const {
        return (a < (int) order.size() ? order[a] : 0);
    }
    void radix_sort(int k) {
        vector<int> frq(n), tmp(n);
        for (auto &it : suf)
            frq[getOrder(it + k)]++;
        for (int i = 1; i < n; i++)
            frq[i] += frq[i - 1];
        for (int i = n - 1; i >= 0; i--)
            tmp[--frq[getOrder(suf[i] + k)]] = suf[i];
        suf = tmp;
    }
public:
    int n;
    string s;
    vector<int> suf, lcp, order; // order store position of suffix i in suf array
    suffix_array(const string &s) :
        n(s.size() + 1), s(s) {
        suf = order = vector<int>(n);
        vector<int> newOrder(n);
        for (int i = 0; i < n; i++)
            suf[i] = i;
        { //sort according to first character
            vector<int> tmp(n);
            for (int i = 0; i < n; i++)
                tmp[i] = s[i];
            sort(all(tmp));
            for (int i = 0; i < n; i++)
                order[i] = (lower_bound(all(tmp), s[i]) - tmp.begin());
        }
        for (int len = 1; newOrder.back() != n - 1; len <= 1) {
            auto cmp = [&](const int &a, const int &b) {
                if (order[a] != order[b])
                    return order[a] < order[b];
                return getOrder(a + len) < getOrder(b + len);
            };
            //sort(all(suf), cmp); //run in 576ms (n<=4e5)
            radix_sort(len); //sort second part
            radix_sort(0); //sort first part
            newOrder[0] = 0;
            for (int i = 1; i < n; i++)
                newOrder[i] = newOrder[i - 1] + cmp(suf[i - 1], suf[i]);
            for (int i = 0; i < n; i++)
                order[suf[i]] = newOrder[i];
        }
        buildLCP();
    }
}
```

```

/*
 * longest common prefix
 * O(n)
 * lcp[i] = lcp(suf[i],suf[i-1])
 */
void buildLCP() {
    lcp = vector<int>(n);
    int k = 0;
    for (int i = 0; i < n - 1; i++) {
        int pos = order[i];
        int j = suf[pos - 1];
        while (s[i + k] == s[j + k])
            k++;
        lcp[pos] = k;
        if (k)
            k--;
    }
}

int LCP_by_order(int a, int b) {
    if (a > b)
        swap(a, b);
    int mn = n - suf[a] - 1;
    for (int k = a + 1; k <= b; k++)
        mn = min(mn, lcp[k]);
    return mn;
}

//LCP(i,j) : longest common prefix between suffix i and suffix j
int LCP(int i, int j) {
    //return LCP_by_order(order[i],order[j]);
    if (order[j] < order[i])
        swap(i, j);
    int mn = n - i - 1;
    for (int k = order[i] + 1; k <= order[j]; k++)
        mn = min(mn, lcp[k]);
    return mn;
}

//compare s[a.first..a.second] with s[b.first..b.second]
//-1:a<b,0:a==b,1:a>b
int compare_substrings(pair<int, int> a, pair<int, int> b) {
    int lcp = min({ LCP(a.first, b.first), a.second - a.first + 1, b.second - b.first + 1 });
    a.first += lcp;
    b.first += lcp;
    if (a.first <= a.second) {
        if (b.first <= b.second) {
            if (s[a.first] == s[b.first])
                return 0;
            return (s[a.first] < s[b.first] ? -1 : 1);
        }
        return 1;
    }
    return (b.first <= b.second ? -1 : 0);
}

```



```

pair<int, int> find_string(const string &x) {
    int st = 0, ed = n;
    for (int i = 0; i < sz(x) && st < ed; i++) {
        auto cmp = [&](int a, int b) {
            if (a == -1)
                return x[i] < s[b + i];
            return s[a + i] < x[i];
        };
        st = lower_bound(suf.begin() + st, suf.begin() + ed, -1, cmp)
            - suf.begin();
        ed = upper_bound(suf.begin() + st, suf.begin() + ed, -1, cmp)
            - suf.begin();
    }
    return {st, ed-1};
}

ll number_of_different_substrings(string s) {
    int n = s.size();
    suffix_array sa(s);
    ll cnt = 0;
    for (int i = 0; i <= n; i++)
        cnt += n - sa.suf[i] - sa.lcp[i];
    return cnt;
}

string longest_common_substring(const string &s1, const string &s2) {
    suffix_array sa(s1 + "#" + s2);
    vector<int> suf = sa.suf, lcp = sa.lcp;
    auto type = [&](int idx) {
        return idx <= s1.size();
    };
    int mx = 0, idx = 0;
    int len = s1.size() + 1 + s2.size();
    for (int i = 1; i <= len; i++)
        if (type(suf[i - 1]) != type(suf[i]) && lcp[i] > mx) {
            mx = lcp[i];
            idx = min(suf[i - 1], suf[i]);
        }
    return s1.substr(idx, mx);
}

int longest_common_substring(const vector<string> &v) {
    int n = v.size();
    int len = n - 1;
    for (auto &it : v)
        len += it.size();
    string s(len, '.');
    vector<int> type(len + 1, n), frq(n + 1);
    for (int i = 0, j = 0; i < v.size(); i++) {
        if (i)
            s[j] = 'z' + i;

```

```

    for (char ch : v[i]) {
        s[j] = ch;
        type[j] = i;
        j++;
    }
}
suffix_array sa(s);
vector<int> suf = sa.suf, lcp = sa.lcp;
monoqueue q;
int st = 0, ed = 0, cnt = 0, mx = 0;
while (st <= s.size()) {
    while (ed <= s.size() && cnt < v.size()) {
        q.push(lcp[ed], ed);
        if (++frq[type[suf[ed]]] == 1)
            cnt++;
        ed++;
    }
    q.pop(st);
    if (cnt == v.size())
        mx = max(mx, q.getMin()); //st+1,ed
    if (--frq[type[suf[st]]] == 0)
        cnt--;
    st++;
}
return mx;
}
string kth_substring(string s, int k) { //1-based, repated
    int n = s.size();
    suffix_array sa(s);
    vector<int> suf = sa.suf, lcp = sa.lcp;
    for (int i = 1; i <= n; i++) {
        int len = n - suf[i];
        int cnt = 0;
        for (int l = 1; l <= len; l++) {
            cnt++;
            int st = i + 1, ed = n, ans = i;
            while (st <= ed) {
                int md = st + ed >> 1;
                if (sa.LCP_by_order(i, md) >= l)
                    st = md + 1, ans = md;
                else
                    ed = md - 1;
            }
            cnt += ans - i;
            if (cnt >= k)
                return s.substr(suf[i], l);
        }
        k -= len;
    }
    assert(0);
}

```

Suffix array Faster

```
class suffix_array {
    const static int alpha = 128;
    int getOrder(int a) const {
        return (a < (int) order.size() ? order[a] : 0);
    }
public:
    int n;
    string s;
    vector<int> suf, order, lcp; // order store position of suffix i in suf array
    suffix_array(const string &s) : n(s.size() + 1), s(s) {
        suf = order = lcp = vector<int>(n);
        vector<int> bucket_idx(n), newOrder(n), newsuff(n);
        vector<int> prev(n), head(alpha, -1);
        for (int i = 0; i < n; i++) {
            prev[i] = head[s[i]];
            head[s[i]] = i;
        }
        int buc = -1, idx = 0;
        for (int i = 0; i < alpha; i++) {
            if (head[i] == -1)
                continue;
            bucket_idx[++buc] = idx;
            for (int j = head[i]; ~j; j = prev[j])
                suf[idx++] = j, order[j] = buc;
        }
        int len = 1;
        do {
            auto cmp = [&](int a, int b) {
                if (order[a] != order[b])
                    return order[a] < order[b];
                return getOrder(a + len) < getOrder(b + len);
            };
            for (int i = 0; i < n; i++) {
                int j = suf[i] - len;
                if (j < 0)
                    continue;
                newsuff[bucket_idx[order[j]]++] = j;
            }
            for (int i = 1; i < n; i++) {
                suf[i] = newsuff[i];
                bool cmpres = cmp(suf[i - 1], suf[i]);
                newOrder[suf[i]] = newOrder[suf[i - 1]] + cmpres;
                if (cmpres)
                    bucket_idx[newOrder[suf[i]]] = i;
            }
            order = newOrder;
            len <<= 1;
        } while (order[suf[n - 1]] != n - 1);
    }
};
```

Z algorithm

```
/*
 * z[i] equal the length of the longest substring starting from s[i]
 * which is also a prefix of s
 */
vector<int> z_algo(string s) {
    int n = s.size();
    vector<int> z(n);
    z[0] = n;
    for (int i = 1, L = 1, R = 1; i < n; i++) {
        int k = i - L;
        if (z[k] + i >= R) {
            L = i;
            R = max(R, i);
            while (R < n && s[R - L] == s[R])
                R++;
            z[i] = R - L;
        } else
            z[i] = z[k];
    }
    return z;
}
```

Math

Combinatorics

```
/*
 * nCr = n!/((n-r)! * r!)
 * nCr(n,r) = nCr(n,n-r)
 * nPr = n!/(n-r)!
 * nPr(circle) = nPr/r
 * nCr(n,r) = pascal[n][r]
 * catalan[n] = nCr(2n,n)/(n+1)
 */

ull nCr(int n, int r) {
    if (r > n)
        return 0;
    r = max(r, n - r);
    ull ans = 1, div = 1, i = r + 1;
    while (i <= n) {
        ans *= i++;
        ans /= div++;
    }
    return ans;
}

ull nPr(int n, int r) {
    if (r > n)
        return 0;
    ull p = 1, i = n - r + 1;
    while (i <= n)
        p *= i++;
    return p;
}

vector<vector<ull>> pascalTriangle(int n) {
```

```

vector<vector<ull>> pascal(n + 1, vector<ull>(n + 1));
for (int i = 0; i <= n; i++) {
    pascal[i][i] = pascal[i][0] = 1;
    for (int j = 1; j < n; j++)
        pascal[i][j] = pascal[i - 1][j] + pascal[i - 1][j - 1];
}
return pascal;
}

// return catalan number n-th using dp O(n^2)//max = 35 then overflow
vector<ull> catalanNumber(int n) {
    vector<ull> catalan(n + 1);
    catalan[0] = catalan[1] = 1;
    for (int i = 2; i <= n; i++) {
        ull& rt = catalan[i];
        for (int j = 0; j < n; j++)
            rt += catalan[j] * catalan[n - j - 1];
    }
    return catalan;
}

// count number of paths in matrix n*m
// go to right or down only
ull countNumberOfPaths(int n, int m) {
    return nCr(n + m - 2, n - 1);
}

```

NCR pre calculation

```

const int N = 1e5 + 100;
const int mod = 1e9 + 7;
ll fact[N];
ll inv[N]; //mod inverse for i
ll invfact[N]; //mod inverse for i!
void factInverse() {
    fact[0] = inv[1] = fact[1] = invfact[0] = invfact[1] = 1;
    for (long long i = 2; i < N; i++) {
        fact[i] = (fact[i - 1] * i) % mod;
        inv[i] = mod - (inv[mod % i] * (mod / i) % mod);
        invfact[i] = (inv[i] * invfact[i - 1]) % mod;
    }
}
ll nCr(int n, int r) {
    if (r > n)
        return 0;
    return (((fact[n] * invfact[r]) % mod) * invfact[n - r]) % mod;
}

```

Matrices

```

typedef vector<int> row;
typedef vector<row> matrix;

matrix initial(int n, int m, int val = 0) {
    return matrix(n, row(m, val));
}

matrix identity(int n) {
    matrix rt = initial(n, n);
    for (int i = 0; i < n; i++)rt[i][i] = 1;
    return rt;
}

matrix addIdentity(const matrix& a) {
    matrix rt = a;

```

```

    for (int i = 0; i < sz(a); i++)rt[i][i] += 1;
    return rt;
}

matrix add(const matrix& a, const matrix& b) {
    matrix rt = initial(sz(a), sz(a[0]));
    for (int i = 0; i < sz(a); i++)for (int j = 0; j < sz(a[0]); j++)
        rt[i][j] = a[i][j] + b[i][j];
    return rt;
}

matrix multiply(const matrix& a, const matrix& b) {
    matrix rt = initial(sz(a), sz(b[0]));
    for (int i = 0; i < sz(a); i++) for (int k = 0; k < sz(a[0]); k++) {
        if (a[i][k] == 0)continue;
        for (int j = 0; j < sz(b[0]); j++)
            rt[i][j] += a[i][k] * b[k][j];
    }
    return rt;
}

matrix power(const matrix& a, ll k) {
    if (k == 0)return identity(sz(a));
    if (k & 1)return multiply(a, power(a, k - 1));
    return power(multiply(a, a), k >> 1);
}

matrix power_itr(matrix a, ll k) {
    matrix rt = identity(sz(a));
    while (k) {
        if (k & 1)rt = multiply(rt, a);
        a = multiply(a, a); k >>= 1;
    }
    return rt;
}

matrix sumPower(const matrix& a, ll k) {
    if (k == 0)return initial(sz(a), sz(a));
    if (k & 1)return multiply(a, addIdentity(sumPower(a, k - 1)));
    return multiply(sumPower(a, k >> 1), addIdentity(power(a, k >> 1)));
}

matrix sumPowerV2(const matrix& a, ll k) {
    int n = sz(a);
    matrix rt = initial(2 * n, 2 * n);
    for (int i = 0; i < 2 * n; i++)
        for (int j = 0; j < n; j++)
            rt[i][j] = a[i % n][j];
    for (int i = n; i < 2 * n; i++)rt[i][i] = 1;
    return power(rt, k);
}

```

Matrix class

```

struct matrix {
    using T = int;
    using row = vector<T>;
    vector<vector<T>> v;
    matrix() {}
    matrix(int n, int m, T val = 0) : v(n, row(m, val)) {}
    int size() const {
        return v.size();
    }
    int cols() const {
        return v[0].size();
    }
}

```

```

    }
    matrix operator*(T a) const {
        matrix rt = *this;
        REP(i, rt.size())
            REP(j, rt.cols())
                rt.v[i][j] *= a;
        return rt;
    }
    friend matrix operator*(T a, const matrix& b) {
        return (b * a);
    }
    friend matrix operator+(const matrix& a, const matrix& b) {
        assert(a.size() == b.size() && a.cols() == b.cols());
        matrix rt(a.size(), a.cols());
        REP(i, rt.size())
            REP(j, rt.cols())
                rt.v[i][j] = a.v[i][j] + b.v[i][j];
        return rt;
    }
    friend matrix operator*(const matrix& a, const matrix& b) {
        assert(a.cols() == b.size());
        matrix rt(a.size(), b.cols());
        REP(i, rt.size())
            REP(k, a.cols())
            {
                if (a.v[i][k] == 0)
                    continue;
                REP(j, rt.cols())
                    rt.v[i][j] += a.v[i][k] * b.v[k][j];
            }
        return rt;
    }
};

matrix identity(int n) {
    matrix r(n, n);
    for (int i = 0; i < n; i++)
        r.v[i][i] = 1;
    return r;
}

matrix power(matrix a, long long y) {
    assert(y >= 0 && a.size() == a.cols());
    matrix rt = identity(a.size());
    while (y > 0) {
        if (y & 1)
            rt = rt * a;
        a = a * a;
        y >>= 1;
    }
    return rt;
}

matrix addIdentity(const matrix& a) {
    matrix rt = a;
    REP(i, a.size())
        rt.v[i][i]++;
    return rt;
}

matrix sumPower(const matrix& a, ll k) {
    if (k == 0)
        return matrix(sz(a), sz(a));
    if (k & 1)

```

```

        return a * addIdentity(sumPower(a, k - 1));
    return (sumPower(a, k >> 1) * addIdentity(power(a, k >> 1)));
}

matrix sumPowerV2(const matrix& a, ll k) {
    int n = sz(a);
    matrix rt(2 * n, 2 * n);
    REP(i, n)
        REP(j, n)
        {
            rt.v[i][j] = a.v[i][j];
            rt.v[i + n][j] = a.v[i][j];
        }
    for (int i = n; i < 2 * n; i++)
        rt.v[i][i] = 1;
    return power(rt, k);
}

```

Mod inverse

```

ll power(ll x, ll y, int mod) {
    if (y == 0)
        return 1;
    if (y == 1)
        return x % mod;
    ll r = power(x, y >> 1, mod);
    return (((r * r) % mod) * power(x, y & 1, mod)) % mod;
}

ll modInverse(ll b, ll mod) { // if mod is Prime
    return power(b, mod - 2, mod);
}

ll modInverse(ll b, ll mod) { // if mod is not Prime, g(a,b) must be equal 1
    return power(b, phi_function(mod) - 1, mod);
}

//ax + by = gcd(a, b)
int gcdExtended(int a, int b, int &x, int &y) {
    if (a == 0) {
        x = 0;
        y = 1;
        return b;
    }
    int x1, y1;
    int g = gcdExtended(b % a, a, x1, y1);
    x = y1 - (b / a) * x1;
    y = x1;
    return g;
}

int modInverse(int a, int mod) {
    int x, y;
    int g = gcdExtended(a, mod, x, y);
    assert(g == 1);
    x = (x % mod + mod) % mod;
    return x;
}

```



```

template<typename T>
T inverse(T a, T m) { //tourist code
    T u = 0, v = 1;
    while (a != 0) {
        T t = m / a;
        m -= t * a;
        swap(a, m);
        u -= t * v;
        swap(u, v);
    }
    assert(m == 1);
    return u;
}

```

(a^n)%p=result, return n

```

// (a^n)%p=result,return minimum n
int getPower(int a, int result, int mod) {
    int sq = sqrt(mod);
    map<int, int> mp;
    ll r = 1;
    for (int i = 0; i < sq; i++) {
        if (mp.find(r) == mp.end())
            mp[r] = i;
        r = (r * a) % mod;
    }
    ll tmp = modInverse(r, mod);
    ll cur = result;
    for (int i = 0; i <= mod; i += sq) {
        if (mp.find(cur) != mp.end())
            return i + mp[cur];
        cur = (cur * tmp) % mod; //val/(a^sq)
    }
    return INF;
}

// Returns minimum x for which a ^ x % m = b % m.
// a,m not not coprime
int getPower(int a, int b, int m) {
    a %= m, b %= m;
    int k = 1, add = 0, g;
    while ((g = __gcd(a, m)) > 1) {
        if (b == k)
            return add;
        if (b % g)
            return -1;
        b /= g, m /= g, ++add;
        k = (k * 111 * a / g) % m;
    }

    int n = sqrt(m) + 1;
    int an = 1;
    for (int i = 0; i < n; ++i)
        an = (an * 111 * a) % m;

    unordered_map<int, int> vals;
    for (int q = 0, cur = b; q <= n; ++q) {
        vals[cur] = q;
        cur = (cur * 111 * a) % m;
    }

    for (int p = 1, cur = k; p <= n; ++p) {
        cur = (cur * 111 * an) % m;
    }
}

```

```

        if (vals.count(cur)) {
            int ans = n * p - vals[cur] + add;
            return ans;
        }
    }
    return -1;
}

```

Primes

```

typedef vector<pair<ll, int>> primeFactors;

const int N = 1e8;
bool isPrime[N + 1];
vector<int> prime;
void sieve() {
    memset(isPrime, true, sizeof(isPrime));
    isPrime[0] = isPrime[1] = false;
    for (int i = 4; i <= N; i += 2)
        isPrime[i] = false;
    for (int i = 3; i * i <= N; i += 2)
        if (isPrime[i])
            for (int j = i * i; j <= N; j += i + i)
                isPrime[j] = false;
    for (int i = 1; i <= N; i++)
        if (isPrime[i])
            prime.push_back(i);
}

// generate prime divisors in n
// n = p1^x1 * p2^x2 .... pn^xn
// O(sqrt(n)) // max = 1e16
primeFactors prime_factors(ll n) {
    primeFactors p;
    int idx = 0;
    while (!(n <= N && isPrime[n]) && idx < prime.size()
        && 1LL * prime[idx] * prime[idx] <= n) {
        int cnt = 0;
        while (n % prime[idx] == 0)
            n /= prime[idx], cnt++;
        if (cnt)
            p.push_back({ prime[idx], cnt });
        idx++;
    }
    if (n > 1)
        p.push_back({ n, 1 });
    return p;
}

// return number of Divisors(n) using prime factorization
ll numOfDivisors(primeFactors mp) {
    ll cnt = 1;
    for (auto it : mp)
        cnt *= (it.second + 1);
    return cnt;
}

// return sum of Divisors(n) using prime factorization
ll sumOfDivisors(primeFactors mp) {
    ll sum = 1;
    for (auto it : mp)
        sum *= sumPower(it.first, it.second);
    return sum;
}

ll phi_function(ll n) {
    ll result = n;

```

```

    primeFactors pf = prime_factors(n);
    for (auto& it : pf) {
        ll p = it.first;
        result -= (result / p);
    }
    return result;
}

```

Summations

```

#define numOfDigit(x) 1+(int)(floor(log10(x)))
#define numOfBits(x) 1+(int)(floor(log2(x)))
//return sum of sequence a, a+x , a+2x .... b
ll sumSequence(ll a, ll b, ll x) {
    a = ((a + x - 1) / x) * x;
    b = (b / x) * x;
    return (b + a) * (b - a + x) / (2 * x);
}
ll sumPower(ll x, ll y) { //x^0 + x^1 + x^2 ... x^y
    return (power(x, y + 1) - 1) / (x - 1);
}
// return sum of divisors for all number from 1 to n
//O(n)
ll sumRangeDivisors(int n) {
    ll ans = 0;
    for (int x = 1; x <= n; x++)
        ans += (n / x) * x;
    return ans;
}
// return sum of divisors for all number from 1 to n
// calc 1e9 in 42ms,can calc more but need big integer
ll sumRangeDivisors(ll x) {
    ll ans = 0, left = 1, right;
    for (; left <= x; left = right + 1) {
        right = x / (x / left);
        ans += (x / left) * (left + right) * (right - left + 1) / 2;
    }
    return ans;
}

```

* sum of $q^0 + q^1 + q^2 \dots q^{\text{INF}} = 1/q$ if $(0 < q < 1)$

Calculator

```

bool delim(char c) {
    return c == ' ';
}
bool is_op(char c) {
    return c == '+' || c == '-' || c == '*' || c == '/';
}
bool is_unary(char c) {
    return c == '+' || c == '-';
}
int priority(char op) {
    if (op < 0) // unary operator
        return 3;
    if (op == '+' || op == '-')
        return 1;
    if (op == '*' || op == '/')
        return 2;
    return -1;
}

```

```

}
void process_op(stack<int>& st, char op) {
    if (op < 0) {
        int l = st.top(); st.pop();
        switch (-op) {
            case '+': st.push(l); break;
            case '-': st.push(-l); break;
        }
    } else {
        int r = st.top(); st.pop();
        int l = st.top(); st.pop();
        switch (op) {
            case '+': st.push(l + r); break;
            case '-': st.push(l - r); break;
            case '*': st.push(l * r); break;
            case '/': st.push(l / r); break;
        }
    }
}

int evaluate(string& s) {
    stack<int> st;
    stack<char> op;
    bool may_be_unary = true;
    for (int i = 0; i < (int)s.size(); i++) {
        if (delim(s[i]))
            continue;
        if (s[i] == '(') {
            op.push('(');
            may_be_unary = true;
        } else if (s[i] == ')') {
            while (op.top() != '(') {
                process_op(st, op.top());
                op.pop();
            }
            op.pop();
            may_be_unary = false;
        } else if (is_op(s[i])) {
            char cur_op = s[i];
            if (may_be_unary && is_unary(cur_op))
                cur_op = -cur_op;
            while (!op.empty() && (
                (cur_op >= 0 && priority(op.top()) >= priority(cur_op)) ||
                (cur_op < 0 && priority(op.top()) > priority(cur_op))
            )) {
                process_op(st, op.top());
                op.pop();
            }
            op.push(cur_op);
            may_be_unary = true;
        } else {
            int number = 0;
            while (i < (int)s.size() && isalnum(s[i]))

```

```

        number = number * 10 + s[i++] - '0';
        --i;
        st.push(number);
        may_be_unary = false;
    }
}

while (!op.empty()) {
    process_op(st, op.top());
    op.pop();
}
return st.top();
}

```

Misc

Bitmask

```

bool getBit(ll num, int ind) {
    return ((num >> ind) & 1);
}

ll setBit(ll num, int ind, bool val) {
    return val ? (num | (1LL << ind)) : (num & ~(1LL << ind));
}

ll flipBit(ll num, int ind) {
    return (num ^ (1LL << ind));
}

ll leastBit(ll num) {
    return (num & -num);
}

template<class Int>
Int turnOnLastZero(Int num) {
    return num | num + 1;
}

template<class Int>
Int turnOnLastConsecutiveZeroes(Int num) {
    return num | num - 1;
}

template<class Int>
Int turnOffLastBit(Int num) {
    return num & num - 1;
}

template<class Int>
Int turnOffLastConsecutiveBits(Int num) {
    return num & num + 1;
}

//num%mod, mod is a power of 2
ll Mod(ll num, ll mod) {
    return (num & mod - 1);
}

bool isPowerOfTwo(ll num) {
    return (num & num - 1) == 0;
}

void genAllSubmask(int mask) {
    for (int subMask = mask;; subMask = (subMask - 1) & mask) {
        //code
        if (subMask == 0)
            break;
    }
}

```

```

}
/*
 * __builtin functions:
 * __builtin_popcount -> used to count the number of one's
 * __builtin_clz -> used to count the leading zeros of the integer
 * __builtin_ctz -> used to count the trailing zeros of the integer
 */
int LOG2(int x) { //floor(log2(x))
    return 31 - __builtin_clz(x);
}
int LOG2(long long x) { //floor(log2(x))
    return 63 - __builtin_clzll(x);
}

```

coordinateCompress

```

void coordinateCompress(vector<int>& axes, vector<int>& iTov,
    map<int, int> vToI, int start = 2, int step = 2) {
    for (auto& it : axes)
        vToI[it] = 0;
    iTov.resize(start + step * vToI.size());
    int idx = 0;
    for (auto& it : vToI) {
        it.second = start + step * idx;
        iTov[it.second] = it.first;
        idx++;
    }
}

```

Random numbers

```

//write this line once in top
mt19937_64 rng(chrono::steady_clock::now().time_since_epoch().count()* ((uint64_t) new char | 1));

// use this instead of rand()
long long rnd = uniform_int_distribution<long long>(low, high)(rng);

```

Custom hash

```

struct custom_hash {
    static uint64_t splitmix64(uint64_t x) {
        x += 0x9e3779b97f4a7c15;
        x = (x ^ (x >> 30)) * 0xbf58476d1ce4e5b9;
        x = (x ^ (x >> 27)) * 0x94d049bb133111eb;
        return x ^ (x >> 31);
    }

    // for pair
    size_t operator()(pair<uint64_t, uint64_t> x) const {
        static const uint64_t FIXED_RANDOM = chrono::steady_clock::now().time_since_epoch().count();
        return splitmix64(x.first + FIXED_RANDOM) ^ (splitmix64(x.second + FIXED_RANDOM) >> 1);
    }

    // for single element
    size_t operator()(uint64_t x) const {
        static const uint64_t FIXED_RANDOM = chrono::steady_clock::now().time_since_epoch().count();
        return splitmix64(x + FIXED_RANDOM);
    }
};

```

Max histogram area

```

int maxHistogramArea(vector<int> v) {
    stack<int> st;
    int maxArea = 0, area = 0;
    int i = 0;

```

```

while (i < sz(v)) {
    if (st.empty() || v[st.top()] <= v[i])
        st.push(i++);
    else {
        int top = st.top(); st.pop();
        if (st.empty())
            area = v[top] * i;
        else
            area = v[top] * (i - st.top() - 1);
        maxArea = max(maxArea, area);
    }
}
while (!st.empty()) {
    int top = st.top(); st.pop();
    if (st.empty())
        area = v[top] * i;
    else
        area = v[top] * (i - st.top() - 1);
    maxArea = max(maxArea, area);
}
return maxArea;
}

```

Sorting

```

long long cnt = 0;
vector<int> v, temp;

// e the first index not have in range array
// like end()
template<class T = less<int>>
void merge_sort(int s, int e, T cmp = less<int>()) {
    if (s + 1 >= e)
        return;
    int m = s + (e - s >> 1);
    merge_sort(s, m, cmp);
    merge_sort(m, e, cmp);
    for (int i = s; i < e; i++)
        temp[i] = v[i];
    int i = s, j = m, k = s;
    while (i < m && j < e)
        if (cmp(temp[i], temp[j]))
            v[k++] = temp[i++];
        else
            v[k++] = temp[j++], cnt += j - k;
    while (i < m)
        v[k++] = temp[i++];
    while (j < e)
        v[k++] = temp[j++];
}

// O(n*log(n)/log(base))
// O(n + base) memory
void radix_sort(vector<int>& v, int base) {
    vector<int> tmp(v.size());
    for (int it = 0, p = 1; it < 10; it++, p *= base) {
        vector<int> frq(base);
        for (auto& it : v)
            frq[(it / p) % base]++;
        for (int i = 1; i < base; i++)
            frq[i] += frq[i - 1];
        for (int i = v.size() - 1; i >= 0; i--)
            tmp[--frq[(v[i] / p) % base]] = v[i];
        v = tmp;
    }
}

```

```

    }
}

void quick_sort(int s, int e) {
    if (s >= e)
        return;
    int j = rand() % (e - s + 1) + s;
    swap(v[s], v[j]);
    j = s;
    int pivot = v[s];
    for (int i = s + 1; i <= e; i++)
        if (v[i] <= pivot)
            swap(v[i], v[++j]);
    swap(v[s], v[j]);
    quick_sort(s, j - 1);
    quick_sort(j + 1, e);
}

```

LIS binary Search

```

/* without build
 * make upper_bound if can take equal elements */
int LIS(const vector<int>& v) {
    vector<int> lis(v.size()); //put value less than zero if needed
    int l = 0;
    for (int i = 0; i < sz(v); i++) {
        int idx = lower_bound(lis.begin(), lis.begin() + l, v[i]) - lis.begin();
        if (idx == l)
            l++;
        lis[idx] = v[i];
    }
    return l;
}

void LIS_binarySearch(vector<int> v) {
    int n = v.size();
    vector<int> last(n), prev(n, -1);
    int length = 0;
    auto BS = [&](int val) {
        int st = 1, ed = length, md, rt = length;
        while (st <= ed) {
            md = st + ed >> 1;
            if (v[last[md]] >= val)
                ed = md - 1, rt = md;
            else st = md + 1;
        }
        return rt;
    };
    for (int i = 1; i < n; i++) {
        if (v[i] < v[last[0]])
            last[0] = i;
        else if (v[i] > v[last[length]]) {
            prev[i] = last[length];
            last[++length] = i;
        }
        else {
            int index = BS(v[i]);
            prev[i] = last[index - 1];
            last[index] = i;
        }
    }
    cout << length + 1 << "\n";
    vector<int> out;
    for (int i = last[length]; i >= 0; i = prev[i])

```



```

        out.push_back(v[i]);
reverse(out.begin(), out.end());
for (auto it : out)
    cout << it << endl;
}

```

Mo algorithm

```

int sqrtN; //use a constant value
struct query {
    int l, r, qIdx, block;
    query(int l, int r, int qIdx) :
        l(l), r(r), qIdx(qIdx), block(l / sqrtN) {}
    bool operator <(const query& o) const {
        if (block != o.block)
            return block < o.block;
        return (block % 2 == 0 ? r < o.r : r > o.r);
    }
};

int curL, curR, ans;
vector<query> q;
void add(int index);
void remove(int index);
void solve(int l, int r) {
    while (curL > l)
        add(--curL);
    while (curR < r)
        add(++curR);
    while (curL < l)
        remove(curL++);
    while (curR > r)
        remove(curR--);
}
vector<int> MO(int n) {
    vector<int> rt(q.size());
    ans = curL = curR = 0;
    add(0);
    sort(q.begin(), q.end());
    for (auto it : q) {
        solve(it.l, it.r);
        rt[it.qIdx] = ans;
    }
    return rt;
}

```

floyd cycle detection algorithm

```

template<class IntFunction>
pair<int, int> find_cycle_floyd(IntFunction f, int x0) {
    int tortoise = f(x0), hare = f(f(x0));
    while (tortoise != hare) {
        tortoise = f(tortoise);
        hare = f(f(hare));
    }
    int start = 0;
    tortoise = x0;
    while (tortoise != hare) {
        tortoise = f(tortoise);
        hare = f(hare);
        start++;
    }
    int length = 1;
}

```

```

    hare = f(tortoise);
    while (tortoise != hare) {
        hare = f(hare);
        length++;
    }
    return make_pair(start, length);
}

```

Convex Hull Trick

```

struct Line {
    ll m, c;
    mutable ll p; //p is intersection between cur and next
    bool operator<(const Line &o) const {
        //change to (m>o.m,c < o.c) to get min
        if (m != o.m)
            return m < o.m;
        return c > o.c;
    }
    bool operator<(ll x) const {
        return p < x;
    }
};

```

```

struct LineContainer: multiset<Line, less<>> {
    // (for doubles, use inf = 1/.0, div(a,b) = a/b)
    static const ll inf = LLONG_MAX;
    ll div(ll a, ll b) { // floored division
        return a / b - ((a ^ b) < 0 && a % b);
    }
    bool isect(iterator x, iterator y) {
        if (y == end())
            return x->p = inf, 0;
        if (x->m == y->m)
            x->p = inf;
        else
            x->p = div(y->c - x->c, x->m - y->m);
        return x->p >= y->p;
    }
    void add(ll m, ll c) {
        auto z = insert( { m, c, 0 } ), y = z++, x = y;
        while (isect(y, z))
            z = erase(z);
        if (x != begin() && isect(--x, y))
            isect(x, y = erase(y));
        while ((y = x) != begin() && (--x)->p >= y->p)
            isect(x, erase(y));
    }
    ll query(ll x) {
        assert(!empty());
        auto l = *lower_bound(x);
        return l.m * x + l.c;
    }
}

```

```
};
```

Geometry

```
typedef complex<long double> point;
#define sz(a) ((int)(a).size())
#define all(n) (n).begin(),(n).end()
#define EPS 1e-9
#define OO 1e9
#define PI acos(-1.0)
#define X real()
#define Y imag()
#define vec(a,b) ((b)-(a))
#define polar(r,t) ((r)*exp(point(0,(t))))
#define angle(v) (atan2((v).Y,(v).X))
#define length(v) ((long double)hypot((v).Y,(v).X))
#define lengthSqr(v) (dot(v,v))
#define dot(a,b) ((conj(a)*(b)).real())
#define cross(a,b) ((conj(a)*(b)).imag())
#define rotate(v,t) (polar(v,t))
#define rotateabout(v,t,a) (rotate(vec(a,v),t)+(a))
#define reflect(p,m) ((conj((p)/(m)))*(m))
#define normalize(p) ((p)/length(p))
#define same(a,b) (lengthSqr(vec(a,b))<EPS)
#define mid(a,b) (((a)+(b))/point(2,0))
#define perp(a) (point(-(a).Y,(a).X))
#define colliner pointOnLine
enum STATE {IN, OUT, BOUNDARY};
int dcmp(double x, double y) { return fabs(x - y) <= EPS ? 0 : x < y ? -1 : 1; }
double fixAngle(double A) { return A > 1 ? 1 : (A < -1 ? -1 : A);}
double fixMod(double a, double b) {return fmod(fmod(a, b) + b, b);}
```

pointOnLine

```
bool pointOnLine(const point& a, const point& b, const point& p) {

    return fabs(cross(vec(a, b), vec(a, p))) < EPS;
}
```

pointOnRay

```
inline bool pointOnRay(point a, point b, point p) {
    return dot(vec(a, b), vec(a, p)) > -EPS && pointOnLine(a, b, p);
}
```

pointOnSegment

```
inline bool pointOnSegment(point a, point b, point p) {
    return dot(vec(a, b), vec(a, p)) > -EPS && pointOnLine(a, b, p) && dot(vec(b, a), vec(b, p)) > -EPS;
}
```

return y of point on line given the line and x of this point

```
long double getYfromXforline(point a, point b, long double x) {
    if (a.X == b.X) return b.Y;
    long double m = (a.Y - b.Y) / (a.X - b.X);
    long double c = a.Y - m * a.X;
    return m * x + c;
}
```

return x of point on line given the line and y of this point

```
long double getXfromYforline(point a, point b, long double y) {
    if (a.X == b.X) return b.X;
    long double m = (a.Y - b.Y) / (a.X - b.X);
    long double c = a.Y - m * a.X;
    return (y - c) / m;
}

namespace std {
    bool operator <(const point& a, const point& b) {
        return a.X != b.X ? a.X < b.X : a.Y < b.Y;
    }
    bool operator >(const point& a, const point& b) {
        return a.X != b.X ? a.X > b.X : a.Y > b.Y;
    }
    // sortsegments butome up , note the point of 1 segment must be sorted
    // the functions that coled must be up of this poosition in code
    bool operator <(const vector<point>& a, const vector<point>& b) {
        point p(a[0].X, getYfromXforline(b[0], b[1], a[0].X));
        if (pointOnSegment(b[0], b[1], p)) return a[0].Y < p.Y;
        p = point(a[1].X, getYfromXforline(b[0], b[1], a[1].X));
        if (pointOnSegment(b[0], b[1], p)) return a[1].Y < p.Y;
        p = point(b[0].X, getYfromXforline(a[0], a[1], b[0].X));
        if (pointOnSegment(a[0], a[1], p)) return p.Y < b[0].Y;
        p = point(b[1].X, getYfromXforline(a[0], a[1], b[1].X));
        if (pointOnSegment(a[0], a[1], p)) return p.Y < b[1].Y;
        return max(a[0].Y, a[1].Y) < max(b[0].Y, b[1].Y);
    }
}
```

return the y of a point that falling up segments untile it fall to ground (as water fall)

```
double waterFallOnsegments(vector< vector<point> > v, point p) {
    for (int i = (int)v.size() - 1; i >= 0; i--) {
        double x = p.X, y = getYfromXforline(v[i][0], v[i][1], p.X);
        if (y <= p.Y && pointOnSegment(v[i][0], v[i][1], point(x, y))) {
            if (v[i][0].Y < v[i][1].Y) p = v[i][0];
            else p = v[i][1];
        }
    }
    return p.Y;
}

point readpoint() { long double x, y; cin >> x >> y; return point(x, y); }
void printpoint(point P) { cout << P.X << " " << P.Y; }
// sometimes point is -0.0 it is ronge mmust be 0,0
void fixpoint(point &p) {
    if (p.X < EPS && p.X > -EPS) p = point(0, p.Y);
    if (p.Y < EPS && p.Y > -EPS) p = point(p.X, 0);
}
```

prependecularVecor

```
bool prependecularVec(const point &a, const point &b) {
    return dot(a, b) == 0;
}
```

paralelVector

```
bool paralelVec(const point &a, const point &b) {
    return cross(a, b) == 0;
}
```

check if a point inside the rectangle

```
bool pointInsidReqt(point LD, point RU, point P) {
    //note that ">=" and "<=" not ">" and "<" it based on your problem...
```

```

    return P.X >= LD.X && P.X <= RU.X && P.Y >= LD.Y && P.Y <= RU.Y;
}

```

check if a point inside the circle

```

bool pointInsidCircle(point center, long double rad, point P) {
    long double d = length(vec(center, P));
    return d<rad;//note that " < " not " <= " it based on your problem.....
}

```

check if a point inside the triangle

```

bool pointInsidTrian(point P1, point P2, point P3, point P) {
    long double A = fabs(cross(vec(P1, P2), vec(P1, P3)) / 2);
    long double A1 = fabs(cross(vec(P, P2), vec(P, P3)) / 2);
    long double A2 = fabs(cross(vec(P, P1), vec(P, P3)) / 2);
    long double A3 = fabs(cross(vec(P, P1), vec(P, P2)) / 2);
    //total area==areas of 3 triangles and the point is not in the porder ==>>(A1>0 ,..)
    return fabs(A - A1 - A2 - A3) < EPS&&A1&&A2&&A3;
}

```

line using it's a, b, c

```

struct line {
    long double a, b, c;
    line(point p1, point p2) {
        if (abs(p1.X - p2.X) < EPS) { a = 1.0; b = 0.0; c = -p1.X; }
        else {
            a = -(long double)(p1.Y - p2.Y) / (p1.X - p2.X);
            b = 1.0;
            c = -(long double)(a * p1.X) - p1.Y;
        }
    }
};

```

Point To Segment

```

point pointToSegment(point p0, point p1, point p2) {
    ld d1, d2;
    point v1 = p1 - p0, v2 = p2 - p0;
    if ((d1 = dp(v1, v2)) <= 0) return p0;
    if ((d2 = dp(v1, v1)) <= d1) return p1;
    ld t = d1 / d2;
    return (p0 + v1 * t);
}

```

check if to lines are parallel

```

bool areParallel(line l1, line l2) {
    return abs(l1.a - l2.a) < EPS && abs(l1.b - l2.b) < EPS;
}

```

check if to lines are the same

```

bool areSame(line l1, line l2) {
    return areParallel(l1, l2) && abs(l1.c - l2.c) < EPS;
}

```

check if to lines are the same using points

```

bool samellLine(const point &a1, const point &b1,const point &a2, const point &b2)
{
    return paralelVec(vec(a1,b1),vec(a2,b2))&&pointOnLine(a1,b1,a2);
}

```

check if 2 lines are intersecting

```

int linIntersect(point a, point b, point p, point q, point &ret) {

```

```

line l1(a, b), l2(p, q);
if (areParallel(l1, l2)) return areSame(l1, l2) ? 2 : 0;           // no intersection
// solve system of 2 linear algebraic equations with 2 unknowns
double x, y;
x = (l2.b * l1.c - l1.b * l2.c) / (l2.a * l1.b - l1.a * l2.b);
// special case: test for vertical line to avoid division by zero
if (abs(l1.b) > EPS) y = -(l1.a * x + l1.c);
else y = -(l2.a * x + l2.c);
ret = point(x, y);
return 1;}

```

get angle (AOB): in radian

```

double angl(point a, point o, point b) {
    point oa = vec(o, a), ob = vec(o, b);
    return acos(dot(oa, ob) / sqrt(norm_sq(oa) * norm_sq(ob)));
}
// wr answer in team formation :D
double getAngle_A_abc(double a, double b, double c) {
    return acos(fixAngle((b * b + c * c - a * a) / (2 * b * c)));
}
// sin(A)/a = sin(B)/b = sin(C)/c
// a^2 = b^2 + c^2 - 2b*c*cos(A)

```

Triangle side given other side and angle

```

double getSide_a_bAB(double b, double A, double B) {
    return (sin(A) * b) / sin(B);
}

```

Triangle angel given other side and angle

```

double getAngle_A_abB(double a, double b, double B) {
    return asin(fixAngle((a * sin(B)) / b));
}

```

Line Inside Rectangle

```

bool lineInsideRectangle(double x1, double x2, double y1, double y2, point st, point ed) {
    if (x2 < x1) swap(x1, x2);
    if (y2 < y1) swap(y1, y2);
    double mnX = min(st.X, ed.X), mxX = max(st.X, ed.X),
           mnY = min(st.Y, ed.Y), mxY = (st.Y, ed.Y);
    return dcmp(x1, mnX) <= 0 && dcmp(x2, mxX) >= 0 && dcmp(y1, mnY) <= 0 && dcmp(y2, mxY) >= 0;
}

```

check if 2 segments intersect

```

bool segmentIntersect(point a, point b, point p, point q, point &ret) {
    int ans = linIntersect(a, b, p, q, ret);
    if (ans == 0) return 0;
    // if we check on ray we must use pointOnray() insted of pointOnSegment
    if (ans == 1) return pointOnSegment(a, b, ret) && pointOnSegment(p, q, ret);
    if (a > b) swap(a, b);
    if (p > q) swap(p, q);
    if (b < p || q < a) return 0;
    ret = max(a, q); return 1;
}

```

check if a line intersects with a rectangle using its (left down) and (right up) points

```

bool linReqtIntersect(point LD, point RU, point a, point b) {
    point ret;
    point LU = point(LD.X, RU.Y);
    point RD = point(RU.X, LD.Y);
    if (pointInsidReqt(LD, RU, a)) return 1;
}

```

```

    if (pointInsidReqt(LD, RU, b))return 1;
    if (segmentIntersect(LU, RU, a, b, ret))return 1;
    if (segmentIntersect(LD, RD, a, b, ret))return 1;
    if (segmentIntersect(LD, LU, a, b, ret))return 1;
    if (segmentIntersect(RD, RU, a, b, ret))return 1;
    return 0;
}
double norm_sq(point v) { return v.X * v.X + v.Y * v.Y; }

```

convert the angle from degree to radian

```
double toRad(double d) { return (d * PI) / 180.0; }
```

convert the angle from radian to degree

```
double toDeg(double d) {
    if (d < 0) d += 2 * PI; return (d * 180 / PI);
}

```

find angle Anticlockwise from v1 to v2

```
double getAngle_2vec(point v1, point v2) {
    return toDeg(atan2(cross(v1, v2), dot(v1, v2)));
}

```

find angle p2p0p1, anti-clock p0p1 to p0p2

```
double getAngle_3points(point p0, point p1, point p2) {
    return getAngle_2vec(vec(p0, p1), vec(p0, p2));
}

```

get vector as a point from it length and angle

```
point getvec(double r, double ang) {
    //if the angle in degree
    ang = toRad(ang);
    double x = cos(ang)*r;
    double y = sin(ang)*r;
    return point(x, y);
}
point scale(point v, double r) {
    return point(v.X*r, v.Y*r);
}

```

get vector with length R according to a Ray ab

```
point getVectorWithLengthR(point a, point b, double r) {
    return scale(normalize(vec(a, b)), r); }

```

get triangle Area using 3 points

```
long double triangleArea3points(const point& a, const point& b, const point& c) {
    return fabs(cross(a, b) + cross(b, c) + cross(c, a)) / 2;
}

```

given the area of rectangle using 3 medians

```
double traingleArea_medians(double m1, double m2, double m3) {
    if (m1 <= 0.0 || m2 <= 0.0 || m3 <= 0.0)return -1; //impossipole
    double s = 0.5*(m1 + m2 + m3);
    double midian_area = (s*(s - m1)*(s - m2)*(s - m3));
    double area = 4.0 / 3.0*sqrt(midian_area);
    if (midian_area <= 0.0 || area <= 0.0)return -1; //impossipole
    return area;
}

```

check Overlapping Rectangles using (left down) and (right up) point for each

```
bool overlapReqt(point LD1, point RU1, point LD2, point RU2, point &LD3, point &RU3) {
```

```

    long double x, y;
    x = max(LD1.X, LD2.X);
    y = max(LD1.Y, LD2.Y);
    LD3 = point(x, y); // the left down poitn for the new rectangle
    x = min(RU1.X, RU2.X);
    y = min(RU1.Y, RU2.Y);
    RU3 = point(x, y); // the left right up for the new rectangle
    return LD3.X < RU3.X && LD3.Y < RU3.Y;
}

```

Given are the (x, y) coordinates of the endpoints of two adjacent sides of a parallelogram. Find the (x, y) coordinates of the fourth point.

```

point getForthPoint(point a1, point a2, point b1, point b2) {
    if (same(a1, b1)) return a2 + vec(b1, b2);
    if (same(a1, b2)) return a2 + vec(b2, b1);
    if (same(a2, b1)) return a1 + vec(b1, b2);
    return a1 + vec(b2, b1);
}

```

get all possible points that complete the parallelogram with another 3 points(triangle)

```

vector<point> getParalel_Tria(point p1, point p2, point p3) {
    vector<point> v(3);
    v[0] = p3 + vec(p2, p1);
    v[1] = p1 + vec(p3, p2);
    v[2] = p3 + vec(p1, p2);
    return v; //each point from them can added to the old 3 points to get the paralelogram
}

```

check if a polygon with angles = A is regular polygon

```

bool isRegulPoleg_Angle(double A) {
    for (int i = 3; i < 400; i++)
        if (A == ((i - 2.0)*180.0) / i) return 1;
    return 0;
}

```

Check if 4 point create a Rectangle

```

// the order needed colocwise
bool isRect(point a, point b, point c, point d){
    return vec(a, b) == vec(d, c) && vec(a, d) == vec(b, c) && prependecularVec(vec(a, b), vec(a, d));
}

```

Check if 4 point create a Square

```

// the order needed colocwise
bool isSquar(point a, point b, point c, point d){
    return vec(a, b) == vec(d, c) && vec(a, d) == vec(b, c)
        && lengthSqr(vec(a, d)) == lengthSqr(vec(a, b)) && prependecularVec(vec(a, b), vec(a, d));
}

```

Point distance to Line

```

double pointDistToLine(point p, point a, point b, point &c) { //line a,b
    // formula: c = a + u * ab
    point ap = vec(a, p), ab = vec(a, b);
    long double u = dot(ap, ab) / lengthSqr(ab);
    c = translate(a, scale(ab, u)); // translate a to c
    return dist(p, c); }

```

Point distance to segment

```

// dis p to ab
double pointDistToLineSegment(point p, point a, point b, point &c) {
    point ap = vec(a, p), ab = vec(a, b);
    long double u = dot(ap, ab) / lengthSqr(ab);
}

```



```

    if (u < 0.0) { // closer to a
        c = point(a.X, a.Y); return dist(p, a);
    } // Euclidean distance between p and a
    if (u > 1.0) { // closer to b
        c = point(b.X, b.Y); return dist(p, b);
    } // Euclidean distance between p and b
    c = translate(a, scale(ab, u)); // translate a to c //between a,b
    return dist(p, c);
}

```

given 2 diagonal points for the square find the other two

```

void square_points(point p1, point p3, point& p2, point& p4) {
    // center point
    ld cx = (p1.X + p3.X) / 2.;
    ld cy = (p1.Y + p3.Y) / 2.;
    // half-diagonal
    ld dx = (p1.X - p3.X) / 2.;
    ld dy = (p1.Y - p3.Y) / 2.;
    ld x2 = cx - dy, y2 = cy + dx;    // second corner
    ld x4 = cx + dy, y4 = cy - dx;    // Fourth corner
    p2 = point(x2, y2);
    p4 = point(x4, y4);
    return;
}

```

Circle rad given 2 points and cen

```

bool circle2PtsRad(point p1, point p2, double r, point& c) {
    double d2 = (p1.X - p2.X) * (p1.X - p2.X) +
        (p1.Y - p2.Y) * (p1.Y - p2.Y);
    double det = r * r / d2 - 0.25;
    if (det < 0.0) return false;
    double h = sqrt(det);
    c.real((p1.X + p2.X) * 0.5 + (p1.Y - p2.Y) * h);
    c.imag((p1.Y + p2.Y) * 0.5 + (p2.X - p1.X) * h);
    return true;
    // to get the other center, reverse p1 and p2
}

```

circleCircleIntersectionArea

```

ld circleCircleIntersectionArea(point cen1, ld r1, point cen2, ld r2) {
    ld dis = hypot(cen1.X - cen2.X, cen1.Y - cen2.Y);
    if (dis > r1 + r2) return 0;
    if (dis <= fabs(r2 - r1) && r1 >= r2)
        return PI * r2 * r2;
    if (dis <= fabs(r2 - r1) && r1 < r2)
        return PI * r1 * r1;
    ld a = r1 * r1, b = r2 * r2;
    ld ang1 = acos((a + dis * dis - b) / (2 * r1 * dis)) * 2;
    ld ang2 = acos((b + dis * dis - a) / (2 * r2 * dis)) * 2;
    ld ret1 = .5 * b * (ang2 - sin(ang2));
    ld ret2 = .5 * a * (ang1 - sin(ang1));
    return ret1 + ret2;
}

```

distance between two points in arc

```

double calcArc(point p1, point p2, point cen) {
    double d = length(vec(p1, p2));
    double ang = (angle(vec(cen, p1)) - angle(vec(cen, p2))) * 180 / PI;
    if (ang < 0) ang += 360;
    ang = min(ang, 360 - ang);
    return r * ang * PI / 180;
}

```

Segment and Segment intersection

```
bool onSegment(point p, point q, point r) {
    if (q.X <= max(p.X, r.X) && q.X >= min(p.X, r.X) &&
        q.Y <= max(p.Y, r.Y) && q.Y >= min(p.Y, r.Y))
        return true;
    return false;
}

ld orientation(point p, point q, point r) {
    ld val = (q.Y - p.Y) * (r.X - q.X) - (q.X - p.X) * (r.Y - q.Y);
    if (val == 0) return 0;
    return (val > 0) ? 1 : 2;
}

bool doIntersect(point p1, point q1, point p2, point q2) {
    ld o1 = orientation(p1, q1, p2);
    ld o2 = orientation(p1, q1, q2);
    ld o3 = orientation(p2, q2, p1);
    ld o4 = orientation(p2, q2, q1);
    if (fabs(o1 - o2) > EPS && fabs(o3 - o4) > EPS)
        return true;
    if (o1 == 0 && onSegment(p1, p2, q1)) return true;
    if (o2 == 0 && onSegment(p1, q2, q1)) return true;
    if (o3 == 0 && onSegment(p2, p1, q2)) return true;
    if (o4 == 0 && onSegment(p2, q1, q2)) return true;
    return false;
}
```

3D geometry

```
// give the sperical distance between 2 points using 2 angels for each (long, lat)
double spherical_distance(double lat1, double lon1, double lat2, double lon2, double rad) {
    double dlon = lon2 - lon1;
    double dlat = lat2 - lat1;
    double a = pow((sin(dlat / 2)), 2) + cos(lat1) * cos(lat2) * pow(sin(dlon / 2), 2);
    double c = 2 * atan2(sqrt(a), sqrt(1 - a));
    return rad * c;
}
```

3D Point

```
struct point3D{
    long double x, y, z;
    point3D(){};
    point3D(long double x1, long double y1, long double z1){
        x = x1; y = y1; z = z1;
    }
    bool read(){ if (cin >> x >> y >> z) return 1; return 0; }
    long double dis(point3D other){
        return sqrt(pow(x - other.x, 2) + pow(y - other.y, 2) + pow(z - other.z, 2));
    }
};
```

The volume of Triangular Pyramid

```
long double cosRule(long double a, long double b, long double c){
    // Handle denom = 0
    long double res = (b * b + a * a - c*c) / (2 * b * a);
    if (res > 1)
        res = 1;
    if (res < -1)
        res = -1;
    return res;
}
```

```

ld triangularPyramidVolume(ld AB, ld AC, ld BC, ld AD, ld BD, ld CD){
    ld cos1 = cosRule(AD, BD, AB),cos2 = cosRule(BD, CD, BC),cos3 = cosRule(CD, AD, AC);
    ld temp = sqrt(1 + 2 * cos1 * cos2 * cos3 - cos1*cos1 - cos2*cos2 - cos3*cos3);
    return AD * BD * CD * temp / 6;
}

long double pyramidVolume(long double ab, long double ac, long double ad,
    long double bc, long double bd, long double cd) {
    long double w = ab, v = ac, u = ad, U = bc, V = bd, W = cd;
    long double X = (w - U + v) * (U + v + w);
    long double x = (U - v + w) * (v - w + U);
    long double Y = (u - V + w) * (V + w + u);
    long double y = (V - w + u) * (w - u + V);
    long double Z = (v - W + u) * (W + u + v);
    long double z = (W - u + v) * (u - v + W);
    long double a = sqrt(x * Y * Z);
    long double b = sqrt(X * y * Z);
    long double c = sqrt(X * Y * z);
    long double d = sqrt(x * y * z);
    long double volume = -a + b + c + d;
    volume *= a - b + c + d;
    volume *= a + b - c + d;
    volume *= a + b + c - d;
    volume = sqrt(volume) / (192.0 * u * v * w);
    return volume;
}

```

Java Scanner

```

static class MScanner {
    StringTokenizer st;
    BufferedReader br;
    public MScanner(InputStream system) {
        br = new BufferedReader(new InputStreamReader(system));
    }

    public MScanner(String file) throws Exception {
        br = new BufferedReader(new FileReader(file));
    }

    public String next() throws IOException {
        while (st == null !st.hasMoreTokens())

```

```

        st = new StringTokenizer(br.readLine());
        return st.nextToken();
    }
    public String nextLine() throws IOException {
        return br.readLine();
    }

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

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

    public char nextChar() throws IOException {
        return next().charAt(0);
    }

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

    public int[] intArr(int n) throws IOException {
        int[] in=new int[n];for(int i=0;in;i++)in[i]=nextInt();
        return in;
    }
    public long[] longArr(int n) throws IOException {
        long[] in=new long[n];for(int i=0;in;i++)in[i]=nextLong();
        return in;
    }
    public int[] intSortedArr(int n) throws IOException {
        int[] in=new int[n];for(int i=0;in;i++)in[i]=nextInt();
        shuffle(in);
        Arrays.sort(in);
        return in;
    }
    public long[] longSortedArr(int n) throws IOException {
        long[] in=new long[n];for(int i=0;in;i++)in[i]=nextLong();
        shuffle(in);
        Arrays.sort(in);
        return in;
    }
    static void shuffle(int[]in) {
        for(int i=0;iin.length;i++) {
            int idx=(int)(Math.random()*in.length);
            int tmp=in[i];
            in[i]=in[idx];
            in[idx]=tmp;
        }
    }
    static void shuffle(long[]in) {

```

```

    for(int i=0;i<in.length;i++) {
        int idx=(int)(Math.random()*in.length);
        long tmp=in[i];
        in[i]=in[idx];
        in[idx]=tmp;
    }
}

public Integer[] IntegerArr(int n) throws IOException {
    Integer[] in=new Integer[n];for(int i=0;i<n;i++)in[i]=nextInt();
    return in;
}

public Long[] LongArr(int n) throws IOException {
    Long[] in=new Long[n];for(int i=0;i<n;i++)in[i]=nextLong();
    return in;
}

public boolean ready() throws IOException {
    return br.ready();
}

public void waitForInput() throws InterruptedException {
    Thread.sleep(3000);
}
}

```