Team notebook

17 de diciembre de 2017

Índice

1. Contest

1.1. C++ Template

```
#include <bits/stdc++.h>
#include <ext/pb_ds/tree_policy.hpp>
#include <ext/pb_ds/assoc_container.hpp>

using namespace std;
using namespace __gnu_pbds;

typedef long long ll;
typedef vector<int> vi;
typedef pair<int, int> pii;
template <class T> using Tree = tree<T, null_type, less<T>,
    rb_tree_tag,tree_order_statistics_node_update>;

#define FOR(i, a, b) for (int i=a; i<(b); i++)
#define F0R(i, a) for (int i=0; i<(a); i++)
#define FORd(i,a,b) for (int i = (b)-1; i >= a; i--)
#define F0Rd(i,a) for (int i = (a)-1; i >= 0; i--)

#define sz(x) (int)(x).size()
#define mp make_pair
#define pb push_back
#define f first
#define s second
#define lb lower_bound
#define ub upper_bound
#define all(x) x.begin(), x.end()

const int MOD = 1000000007;

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

}

// read!read!read!read!read!read!read!
// ll vs. int!
```

1.2. FastScanner

```
/**
* Source: Matt Fontaine?
*/

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

    public FastScanner(InputStream stream) {
        this.stream = stream;
    }
    int read() {
        if (numChars == -1)
            throw new InputMismatchException();
        if (curChar >= numChars) {
            curChar = 0;
            try {
                numChars = stream.read(buf);
            } catch (IOException e) {
                throw new InputMismatchException();
            }
            if (numChars <= 0) return -1;
        }
        return buf[curChar++];
    }

    boolean isSpaceChar(int c) {
```

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

    boolean isEndline(int c) {
        return c == '\n' || c == '\r' || c == -1;
    }

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

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

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

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

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

1.3. troubleshoot

Source: KACTL

Pre-submit:

- Write a few simple test cases, if sample is not enough.
- Are time limits close? If so, generate max cases.
- Is the memory usage fine?
- Could anything overflow?
- Make sure to submit the right file.

Wrong answer:

- Print your solution! Print debug output, as well.
- Are you clearing all datastructures between test cases?
- Can your algorithm handle the whole range of input?
- Read the full problem statement again.
- Do you handle all corner cases correctly?
- Have you understood the problem correctly?
- Any uninitialized variables?
- Any overflows?
- Confusing N and M, i and j, etc.?
- Are you sure your algorithm works?
- What special cases have you not thought of?
- Are you sure the STL functions you use work as you think?
- Add some assertions, maybe resubmit.
- Create some testcases to run your algorithm on.
- Go through the algorithm for a simple case.
- Go through this list again.

- Explain your algorithm to a team mate.
- Ask the team mate to look at your code.
- Go for a small walk, e.g. to the toilet.
- Is your output format correct? (including whitespace)
- Rewrite your solution from the start or let a team mate do it.

Runtime error:

- Have you tested all corner cases locally?
- Any uninitialized variables?
- Are you reading or writing outside the range of any vector?
- Any assertions that might fail?
- Any possible division by 0? (mod 0 for example)
- Any possible infinite recursion?
- Invalidated pointers or iterators?
- Are you using too much memory?
- Debug with resubmits (e.g. remapped signals, see Various).

Time limit exceeded:

- Do you have any possible infinite loops?
- What is the complexity of your algorithm?
- Are you copying a lot of unnecessary data? (References)
- How big is the input and output? (consider scanf)
- Avoid vector, map. (use arrays/unordered map)
- What do your team mates think about your algorithm?

Memory limit exceeded:

- What is the max amount of memory your algorithm should need?
- Are you clearing all data structures between test cases?

2. Data Structures

2.1. (2) Coordinate Compression

```
void compress(vi& x) {
    map<int,int> m;
    for (int i: x) m[i] = 0;

    int co = 0;
    for (auto& a: m) a.s = co++;

    for (int& i: x) i = m[i];
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    vi z = {2,4,3,6};
    compress(z);
    for (int i: z) cout << i << " ";
}
```

2.2. (2) STL Demo

```
struct cmp {
    bool operator()(const int& l, const int& r) const {
        return l > r;
    }
};

struct hsh {
    size_t operator()(const pii& k) const {
        return hash<int>()(k.f)^(hash<int>()(k.s^293849182));
    }
};

set<int,cmp> s;
map<int,int,cmp> m;
unordered_map<pii,int,hsh> u;

int main() {
        cout << "---\nSET\n---\n";
        s.insert(1), s.insert(2);
```

```
    for (int i: s) cout << i << "\n";

    cout << "---\nMAP\n---\n";
    m[1] = 5, m[2] = 10;
    for (pii i: m) cout << i.f << " " << i.s << "\n";
}
```

2.3. (4) Matrix

```
/**
* Source: KACTL
*/

template<int SZ> struct mat {
    array<array<ll,SZ>,SZ> d;

    mat() {
        FOR(i,SZ) FOR(j,SZ) d[i][j] = 0;
    }

    mat operator+(const mat& m) {
        mat<SZ> a;
        FOR(i,SZ) FOR(j,SZ) a.d[i][j] = (d[i][j]+m.d[i][j]) % MOD;
        return a;
    }

    mat operator*(const mat& m) {
        mat<SZ> a;
        FOR(i,SZ) FOR(j,SZ) FOR(k,SZ)
            a.d[i][k] = (a.d[i][k]+d[i][j]*m.d[j][k]) % MOD;
        return a;
    }

    mat operator^(ll p) {
        mat<SZ> a, b(*this);
        FOR(i,SZ) a.d[i][i] = 1;

        while (p) {
            if (p&1) a = a*b;
            b = b*b;
            p /= 2;
        }
        return a;
    }

    void print() {
        FOR(i,SZ) {
            FOR(j,SZ) cout << d[i][j] << " ";
            cout << "\n";
        }
        cout << "------------\n";
    }
};

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        mat<2> x;
        x.d[0][0] = 1, x.d[1][0] = 2, x.d[1][1] = 1, x.d[0][1] = 3;
        x.print();

        mat<2> y = x*x;
        y.print();

        mat<2> z = x^5;
        z.print();
}
```

2.4. 1D Range Queries

2.4.1. (3) BIT

```
// 1D point update, range query

template<int SZ> struct BIT {
    int bit[SZ+1];

    BIT() {
        memset(bit,0,sizeof bit);
    }

    void upd(int k, int val) {
        for( ;k <= SZ; k += (k&-k)) bit[k] += val;
    }

    int query(int k) {
```

```
        int temp = 0;
        for (;k > 0;k -= (k&-k)) temp += bit[k];
        return temp;
    }
    int query(int l, int r) { return query(r)-query(l-1); }
};

int main() {
    BIT<1<<17> b;
    b.upd(5,2);
    b.upd(4,1);
    cout << b.query(3,5) << "\n";
}
```

2.4.2. (3) RMQ

```
template<class T, int SZ> struct RMQ {
    T stor[SZ][31-__builtin_clz(SZ)];

    T comb(T a, T b) {
        return min(a,b);
    }

    void build(vector<T>& x) {
        FOR(i,x.size()) stor[i][0] = x[i];
        FOR(j,1,31-__builtin_clz(SZ)) FOR(i,SZ-(1<<(j-1)))
            stor[i][j] = comb(stor[i][j-1],stor[i+(1<<(j-1))][j-1]);
    }

    T query(int l, int r) {
        int x = 31-__builtin_clz(r-l+1);
        return comb(stor[l][x],stor[r-(1<<x)+1][x]);
    }
};

RMQ<int,100000> R;

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        vi x; FOR(i,10) x.pb(rand()%100);
        FOR(i,10) cout << x[i] << " ";
        cout << "\n";
        R.build(x);
        FOR(i,10) {
            int a = rand() % 10, b = rand() % 10; if (a > b) swap(a,b);
            cout << a << " " << b << " " << R.query(a,b) << "\n";
        }
}
```

2.4.3. (3) SegTree

```
// 1D point update, range query

template<class T, int SZ> struct Seg {
    T seg[2*SZ], MN = 0;

    Seg() {
        memset(seg,0,sizeof seg);
    }

    T comb(T a, T b) { return a+b; } // easily change this to min or max

    void upd(int p, T value) { // set value at position p
        for (seg[p += SZ] = value; p > 1; p >>= 1) seg[p>>1] =
            comb(seg[p],seg[p^1]);
    }

    void build() {
        FORd(i,SZ) seg[i] = comb(seg[2*i],seg[2*i+1]);
    }

    T query(int l, int r) { // sum on interval [l, r]
        T res = MN; r++;
        for (l += SZ, r += SZ; l < r; l >>= 1, r >>= 1) {
            if (l&1) res = comb(res,seg[l++]);
            if (r&1) res = comb(res,seg[--r]);
        }
        return res;
    }
};

int main() {
    Seg<int,1<<17> s;
    s.upd(5,2);
    s.upd(4,1);
    cout << s.query(3,5) << "\n";
```

```
}
```

2.4.4. (4) BIT with Range Update

```
// 1D range update, range query

template<int SZ> struct BIT {
    ll bit[2][SZ+1]; // sums piecewise linear functions

    BIT() { memset(bit,0,sizeof bit); }

    void u(int ind, int hi, int val) {
        for(;hi <= SZ; hi += (hi&-hi)) bit[ind][hi] += val;
    }

    void upd(int hi, int val) {
        u(1,1,val), u(1,hi+1,-val);
        u(0,hi+1,hi*val);
    }
    void upd(int lo, int hi, int val) { upd(lo-1,-val), upd(hi,val); }

    ll qsum(int x) {
        ll c1 = 0, c0 = 0;
        for (int x1 = x; x1 > 0; x1 -= (x1&-x1))
            c1 += bit[1][x1], c0 += bit[0][x1];
        return c1*x+c0;
    }
    ll qsum(int x, int y) { return qsum(y)-qsum(x-1); }
};

int main() {
    BIT<1<<17> bit;
    bit.upd(2,5,7);
    cout << bit.qsum(1,2) << " " << bit.qsum(4,6) << "\n"; // 7 14
}
```

2.4.5. (4) Lazy SegTree

```
// 1D range update, range query
// Inspiration: USACO Counting Haybales

const ll INF = MOD; // change if ll ...

template<class T, int SZ> struct LazySegTree {
    T sum[2*SZ], mn[2*SZ], lazy[2*SZ]; // set SZ to a power of 2

    LazySegTree() {
        memset (sum,0,sizeof sum);
        memset (mn,0,sizeof mn);
        memset (lazy,0,sizeof lazy);
    }

    void push(int ind, int L, int R) {
        sum[ind] += (R-L+1)*lazy[ind];
        mn[ind] += lazy[ind];
        if (L != R) lazy[2*ind] += lazy[ind], lazy[2*ind+1] += lazy[ind];
        lazy[ind] = 0;
    }

    void pull(int ind) {
        sum[ind] = sum[2*ind]+sum[2*ind+1];
        mn[ind] = min(mn[2*ind],mn[2*ind+1]);
    }

    void build() {
        FORd(i,SZ) pull(i);
    }

    T qsum(int lo, int hi, int ind = 1, int L = 0, int R = SZ-1) {
        push(ind,L,R);
        if (lo > R || L > hi) return 0;
        if (lo <= L && R <= hi) return sum[ind];

        int M = (L+R)/2;
        return qsum(lo,hi,2*ind,L,M)+qsum(lo,hi,2*ind+1,M+1,R);
    }

    T qmin(int lo, int hi, int ind = 1, int L = 0, int R = SZ-1) {
        push(ind,L,R);
        if (lo > R || L > hi) return INF;
        if (lo <= L && R <= hi) return mn[ind];

        int M = (L+R)/2;
        return min(qmin(lo,hi,2*ind,L,M),qmin(lo,hi,2*ind+1,M+1,R));
    }
```

```
    void upd(int lo, int hi, ll inc, int ind = 1, int L = 0, int R =
        SZ-1) {
        push(ind,L,R);
        if (hi < L || R < lo) return;
        if (lo <= L && R <= hi) {
            lazy[ind] = inc;
            push(ind,L,R);
            return;
        }

        int M = (L+R)/2;
        upd(lo,hi,inc,2*ind,L,M); upd(lo,hi,inc,2*ind+1,M+1,R);
        pull(ind);
    }
};

int main() {
    LazySegTree<int,1<<17> seg;
    seg.upd(2,5,7);
    cout << seg.qsum(1,2) << " " << seg.qsum(4,6) << " " << seg.qmin(3,4)
        << "\n"; // 7 14 7
}
```

2.4.6. (5) Lazy Persistent SegTree

```
struct Node { // without lazy updates
    int val = 0;
    Node* c[2];

    Node* copy() {
        Node* x = new Node(); *x = *this;
        return x;
    }

    int query(int low, int high, int L, int R) {
        if (low <= L && R <= high) return val;
        if (R < low || high < L) return MOD;
        int M = (L+R)/2;
        return min(c[0]->query(low,high,L,M),c[1]->query(low,high,M+1,R));
    }

    Node* upd(int ind, int v, int L, int R) {
        if (R < ind || ind < L) return this;
        Node* x = copy();

        if (ind <= L && R <= ind) {
            x->val += v;
            return x;
        }

        int M = (L+R)/2;
        x->c[0] = x->c[0]->upd(ind,v,L,M);
        x->c[1] = x->c[1]->upd(ind,v,M+1,R);
        x->val = min(x->c[0]->val,x->c[1]->val);

        return x;
    }

    void build(vi& arr, int L, int R) {
        if (L == R) {
            if (L < (int)arr.size()) val = arr[L];
            else val = 0;
            return;
        }
        int M = (L+R)/2;
        c[0] = new Node();
        c[0]->build(arr,L,M);
        c[1] = new Node();
        c[1]->build(arr,M+1,R);
        val = min(c[0]->val,c[1]->val);
    }
};

struct node { // with lazy updates
    int val = 0, lazy = 0;
    node* c[2];

    node* copy() {
        node* x = new node(); *x = *this;
        return x;
    }

    void push() {
        if (!lazy) return;
        val += lazy;
        FOR(i,2) if (c[i]) {
            c[i] = new node(*c[i]);
            c[i]->lazy += lazy;
```

```
        }
        lazy = 0;
    }

    int query(int low, int high, int L, int R) {
        if (low <= L && R <= high) return val+lazy;
        if (R < low || high < L) return MOD;
        int M = (L+R)/2;
        return
            lazy+min(c[0]->query(low,high,L,M),c[1]->query(low,high,M+1,R));
    }

    node* upd(int low, int high, int v, int L, int R) {
        push();
        if (R < low || high < L) return this;
        node* x = copy();

        if (low <= L && R <= high) {
            x->lazy = v; x->push();
            return x;
        }

        int M = (L+R)/2;
        x->c[0] = x->c[0]->upd(low,high,v,L,M);
        x->c[1] = x->c[1]->upd(low,high,v,M+1,R);
        x->val = min(x->c[0]->val,x->c[1]->val);

        return x;
    }

    void build(vi& arr, int L, int R) {
        if (L == R) {
            if (L < (int)arr.size()) val = arr[L];
            else val = 0;
            return;
        }
        int M = (L+R)/2;
        c[0] = new node();
        c[0]->build(arr,L,M);
        c[1] = new node();
        c[1]->build(arr,M+1,R);
        val = min(c[0]->val,c[1]->val);
    }
};
```

```
template<int SZ> struct pers {
    node* loc[SZ+1]; // stores location of root after ith update
    int nex = 1;

    pers() { loc[0] = new node(); }

    void upd(int low, int high, int val) {
        loc[nex] = loc[nex-1]->upd(low,high,val,0,SZ-1);
        nex++;
    }
    void build(vi& arr) {
        loc[0]->build(arr,0,SZ-1);
    }
    int query(int ti, int low, int high) {
        return loc[ti]->query(low,high,0,SZ-1);
    }
};

pers<8> p;

int main() {
    vi arr = {1,7,2,3,5,9,4,6};
    p.build(arr);

    p.upd(1,2,2); // 1 9 4 3 5 9 4 6

    FOR(i,8) {
        FOR(j,i,8) cout << p.query(1,i,j) << " ";
        cout << "\n";
    }
    cout << "\n";

    p.upd(4,7,5); // 1 9 4 3 10 14 9 11
    FOR(i,8) {
        FOR(j,i,8) cout << p.query(2,i,j) << " ";
        cout << "\n";
    }
    cout << "\n";

    FOR(i,8) {
        FOR(j,i,8) cout << p.query(1,i,j) << " ";
        cout << "\n";
    }
    cout << "\n";
}
```

2.4.7. (6) Wavelet Tree

```
/**
* Source: https://ideone.com/Tkters
* Unused
*/

int MAX = 1000000;
int a[300000];

struct wavelet {
    int lo, hi;
    wavelet *c[2];
    vi b;

    wavelet(int *from, int *to, int x, int y) {
        lo = x, hi = y;
        if (lo == hi || from >= to) return;
        int mid = (lo+hi)/2;
        auto f = [mid](int x) { return x <= mid; };
        b.pb(0); for (auto it = from; it != to; it++)
            b.pb(b.back()+f(*it));
        auto pivot = stable_partition(from,to,f);
        c[0] = new wavelet(from,pivot,lo,mid);
        c[1] = new wavelet(pivot,to,mid+1,hi);
    }

    int kth(int l, int r, int k) { // kth number in [l,r]
        if (l > r) return 0;
        if (lo == hi) return lo;
        int inLeft = b[r]-b[l-1];
        int lb = b[l-1], rb = b[r];
        if (k <= inLeft) return c[0]->kth(lb+1,rb,k);
        return c[1]->kth(l-lb,r-rb,k-inLeft);
    }

    int LTE(int l, int r, int k) { // less than or equal to k
                if(l > r || k < lo) return 0;
                if(hi <= k) return r-l+1;
                int lb = b[l-1], rb = b[r];
                return c[0]->LTE(lb+1, rb, k)+c[1]->LTE(l-lb, r-rb, k);
        }

        int count(int l, int r, int k) { // equal to k
                if(l > r || k < lo || k > hi) return 0;
                if(lo == hi) return r - l + 1;
                int lb = b[l-1], rb = b[r], mid = (lo+hi)/2;
                if(k <= mid) return c[0]->count(lb+1, rb, k);
                return c[1]->count(l-lb, r-rb, k);
        }
};

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        int i,n,k,j,q,l,r;
        cin >> n;
        FOR(i,n) cin >> a[i+1];
        wavelet T(a+1, a+n+1, 1, MAX);
        cin >> q;
        while (q--){
                int x;
                cin >> x >> l >> r >> k;
                if(x == 0){
                        //kth smallest
                        cout << "Kth smallest: ";
                        cout << T.kth(l, r, k) << endl;
                }
                if(x == 1){
                        //less than or equal to K
                        cout << "LTE: ";
                        cout << T.LTE(l, r, k) << endl;
                }
                if(x == 2){
                        //count occurence of K in [l, r]
                        cout << "Occurence of K: ";
                        cout << T.count(l, r, k) << endl;
                }
        }
}
```

2.5. 2D Range Queries

2.5.1. (4) 2D BIT

```
template<int SZ> struct BIT2D {
    int bit[SZ+1][SZ+1];
    void upd(int X, int Y, int val) {
        for (; X <= SZ; X += (X&-X))
```

```
            for (int Y1 = Y; Y1 <= SZ; Y1 += (Y1&-Y1))
                bit[X][Y1] += val;
    }
    int query(int X, int Y) {
        int ans = 0;
        for (; X > 0; X -= (X&-X))
            for (int Y1 = Y; Y1 > 0; Y1 -= (Y1&-Y1))
                ans += bit[X][Y1];
        return ans;
    }
    int query(int X1, int X2, int Y1, int Y2) {
        return query(X2,Y2)-query(X1-1,Y2)-query(X2,Y1-1)+query(X1-1,Y1-1);
    }
};

int main() {
        BIT2D<1000> x;
        x.upd(2,5,7);
        x.upd(3,6,8);
        x.upd(4,6,9);
        cout << x.query(2,3,5,6);
}
```

2.5.2. (4) 2D Sparse SegTree

```
// 2D Segment Tree and SegBIT
// 2D Point Update, Range Query

const int SZ = 1<<17;

// Sparse 1D SegTree
struct node {
    int val = 0;
    node* c[2];

    void upd(int ind, int v, int L = 0, int R = SZ-1) { // set an element
        equal to v
        if (L == ind && R == ind) { val = v; return; }

        int M = (L+R)/2;
        if (ind <= M) {
            if (!c[0]) c[0] = new node();
            c[0]->upd(ind,v,L,M);
        } else {
            if (!c[1]) c[1] = new node();
            c[1]->upd(ind,v,M+1,R);
        }

        val = 0;
        if (c[0]) val += c[0]->val;
        if (c[1]) val += c[1]->val;
    }

    int query(int low, int high, int L = 0, int R = SZ-1) { // query sum
        of segment
        if (low <= L && R <= high) return val;
        if (high < L || R < low) return 0;

        int M = (L+R)/2, t = 0;
        if (c[0]) t += c[0]->query(low,high,L,M);
        if (c[1]) t += c[1]->query(low,high,M+1,R);
        return t;
    }
};

// 2D SegTree, sparse segtree of sparse 1D segtrees
struct Node {
    node seg;
    Node* c[2];

    void upd(int x, int y, int v, int L = 0, int R = SZ-1) { // set an
        element equal to v
        seg.upd(y,v);
        if (L == x && R == x) return;

        int M = (L+R)/2;
        if (x <= M) {
            if (!c[0]) c[0] = new Node();
            c[0]->upd(x,y,v,L,M);
        } else {
            if (!c[1]) c[1] = new Node();
            c[1]->upd(x,y,v,M+1,R);
        }
    }

    int query(int x1, int x2, int y1, int y2, int L = 0, int R = SZ-1) {
        // query sum of rectangle
        if (x1 <= L && R <= x2) return seg.query(y1,y2);
```

```
        if (x2 < L || R < x1) return 0;

        int M = (L+R)/2, t = 0;
        if (c[0]) t += c[0]->query(x1,x2,y1,y2,L,M);
        if (c[1]) t += c[1]->query(x1,x2,y1,y2,M+1,R);
        return t;
    }
};

// SegTree + BIT
// Array of Sparse Segtrees
struct SegBit {
    node seg[SZ+1];

    void upd(int x, int y, int v) { // set an element equal to v
        for (x++;x <= SZ; x += (x&-x)) seg[x].upd(y,v);
    }

    int query(int x, int y1, int y2) {
        int ret = 0;
        for (;x > 0; x -= (x&-x)) ret += seg[x].query(y1,y2);
        return ret;
    }

    int query(int x1, int x2, int y1, int y2) { // query sum of rectangle
        return query(x2+1,y1,y2)-query(x1,y1,y2);
    }
};

Node n;
SegBit s;

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

    n.upd(5,7,2);
    n.upd(3,2,20);
    n.upd(5,8,200);
    cout << n.query(3,5,2,7) << "\n"; // 22

    s.upd(5,7,2);
    s.upd(3,2,20);
    s.upd(5,8,200);
    cout << s.query(3,5,2,7) << "\n"; // 22
}
```

2.5.3. (4) Merge-Sort Tree

```
template<int SZ> struct mstree {
    Tree<pii> val[SZ+1]; // for offline queries use vector with binary
        search instead

    void upd(int x, int y, int t = 1) { // x-coordinate between 1 and SZ
        inclusive
        for (int X = x; X <= SZ; X += X&-X) {
            if (t) val[X].insert({y,x});
            else val[X].erase({y,x});
        }
    }

    int query(int x, int y) {
        int t = 0;
        for (;x > 0; x -= x&-x) t += val[x].order_of_key({y,MOD});
        return t;
    }

    int query(int lox, int hix, int loy, int hiy) { // query number of
        elements within a rectangle
        return
            query(hix,hiy)-query(lox-1,hiy)-query(hix,loy-1)+query(lox-1,loy-1);
    }
};

int main() {
        mstree<100000> m;
        m.upd(3,6); m.upd(4,5);
        cout << m.query(3,5,4,6) << " " << m.query(3,5,4,5); // 2, 1
}
```

2.6. BBST

2.6.1. (5) Link-Cut Tree

```
int p[100001], pp[100001], c[100001][2], sum[100001];

int getDir(int x, int y) {
    return c[x][0] == y ? 0 : 1;
}
```

```
void setLink(int x, int y, int d) {
    c[x][d] = y, p[y] = x;
}

void rotate(int y, int d) {
    int x = c[y][d], z = p[y];
    setLink(y,c[x][d^1],d);
    setLink(x,y,d^1);
    setLink(z,x,getDir(z,y));

    sum[x] = sum[y];
    sum[y] = sum[c[y][0]]+sum[c[y][1]]+1;
    pp[x] = pp[y]; pp[y] = 0;
}

void splay(int x) {
    while (p[x]) {
        int y = p[x], z = p[y];
        int dy = getDir(y,x), dz = getDir(z,y);
        if (!z) rotate(y,dy);
        else if (dy == dz) rotate(z,dz), rotate(y,dy);
        else rotate(y,dy), rotate(z,dz);
    }
}

void dis(int v, int d) { // fix
    p[c[v][d]] = 0, pp[c[v][d]] = v;
    sum[v] -= sum[c[v][d]];
    c[v][d] = 0;
}

void con(int v, int d) { // fix
    c[pp[v]][d] = v;
    sum[pp[v]] += sum[v];
    p[v] = pp[v], pp[v] = 0;
}

void access(int v) {
    // v is brought to the root of auxiliary tree
    // modify preferred paths

    splay(v);
    dis(v,1);

    while (pp[v]) {
        int w = pp[v]; splay(w);
        dis(w,1), con(v,1);
        splay(v);
    }
}

int find_root(int v) {
    access(v);
    while (c[v][0]) v = c[v][0];
    access(v);
    return v;
}

int find_depth(int v) {
    access(v);
    return sum[c[v][0]];
}

void cut(int v) {
    // cut link between v and par[v]
    access(v);
    pp[c[v][0]] = p[c[v][0]] = 0; // fix
    sum[v] -= sum[c[v][0]];
    c[v][0] = 0;
}

void link(int v, int w) {
    // v, which is root of another tree, is now child of w
    access(v), access(w);
    pp[w] = v; con(w,0);
}

int anc(int v, int num) {
    if (find_depth(v) < num) return 0;
    access(v);
    v = c[v][0];

    while (1) {
        if (sum[c[v][1]] >= num) v = c[v][1];
        else if (sum[c[v][1]]+1 == num) return v;
        else num -= (sum[c[v][1]]+1), v = c[v][0];
    }
}

int main() {
```

```
    FOR(i,1,100001) sum[i] = 1;

    link(2,1);
    link(3,1);
    link(4,1);
    link(5,4);
    link(10,4);
    link(7,6);
    link(8,7);
    link(9,8);

    FOR(i,1,11) cout << i << " " << find_root(i) << " " << find_depth(i)
        << " " << anc(i,2) << "\n";
    cout << "\n";

    cut(4);
    link(4,8);

    FOR(i,1,11) cout << i << " " << find_root(i) << " " << find_depth(i)
        << " " << anc(i,2) << "\n";
}
```

2.6.2. (5) Splay Tree

```
/*
Sources:
* http://codeforces.com/blog/entry/18462
*
    https://sites.google.com/site/kc97ble/container/splay-tree/splaytree-cpp-3
*/

struct node{
    int val, sz;
    node *p, *c[2];
    node (int v) {
        val = v, sz = 1;
    }
    void recalc() {
        sz = 1;
        if (c[0]) sz += c[0]->sz;
        if (c[1]) sz += c[1]->sz;
    }
};

node *root;

void setLink(node *x, node *y, int d) {
    if (x) {
        x->c[d] = y;
        x->recalc();
    }
    if (y) y->p = x;
}

int getDir(node *x, node *y) {
    if (!x) return -1;
    return x->c[0] == y ? 0 : 1;
}

void rot(node *x, int d) {
    node *y = x->c[d], *z = x->p;
    setLink(x, y->c[d^1], d);
    setLink(y, x, d^1);
    setLink(z, y, getDir(z, x));
    x->recalc(), y->recalc();
}

void splay(node *x) {
    while (x->p) {
        node *y = x->p, *z = y->p;
        int dy = getDir(y, x), dz = getDir(z, y);
        if (!z) rot(y, dy);
        else if (dy == dz) rot(z, dz), rot(y, dy);
        else rot(y, dy), rot(z, dz);
    }
    root = x;
}

node* ins(node* cur, int v) {
    if (!cur) return cur = new node(v);
    if (cur->val == v) return cur;
    int t = v < cur->val ? 0 : 1;

    if (!cur->c[t]) {
        setLink(cur,new node(v),t);
        return cur->c[t];
    } else {
        node* x = ins(cur->c[t],v);
```

```
        cur->recalc();
        return x;
    }
}

void ins(int val) {
    splay(ins(root,val));
}

bool find(node *cur, int v) {
    if (!cur) return 0;
    if (cur->val == v) {
        splay(cur);
        return 1;
    }
    return find(cur->c[v < cur->val ? 0 : 1],v);
}

bool del(int v) {
    if (!find(root,v)) return 0;
    node *N = root, *P = N->c[0];
    if(!P) {
        root = N->c[1]; root->p = NULL, delete N;
        return 1;
    }

    while(P->c[1]) P = P->c[1];
    setLink(P,N->c[1],1);
    root = N->c[0], root->p = NULL, delete N;

    while (P) {
        P->recalc();
        P = P->p;
    }
    return 1;
}

void inOrder(node* cur) {
    if (!cur) return;
    cout << "NODE " << cur->val << ": SIZE " << cur->sz << "\n";
    if (cur->c[0]) cout << "LEFT: " << cur->c[0]->val << "\n";
    if (cur->c[1]) cout << "RIGHT: " << cur->c[1]->val << "\n";
    cout << "\n";
    inOrder(cur->c[0]);
    inOrder(cur->c[1]);
}

int main() {
    for (int i = 0; i < 10; ++i) ins(rand() % 50);
    inOrder(root);
    cout << "--------\n\n";
    del(21);
    inOrder(root);
}
```

2.6.3. (5) Treap

```
/**
* Source: KACTL
* Description: easiest BBST
*/

struct tnode {
    ll val, lazy;
    int pri, sz;
    tnode *c[2];

    tnode* copy() {
        tnode* x = new tnode(0); *x = *this;
        return x;
    }

    tnode (ll v) {
        val = v, lazy = 0;
        pri = rand()+(rand()<<15), sz = 1;
        c[0] = c[1] = NULL;
    }

    void propogate() {
        if (!lazy) return;
        val += lazy;
        FOR(i,2) if (c[i]) {
            c[i] = c[i]->copy();
            c[i]->lazy += lazy;
        }
        lazy = 0;
    }
```

```
    void recalc() {
        sz = 1;
        FOR(i,2) if (c[i]) sz += c[i]->sz;
    }

    void inOrder(bool f = 0) {
        propogate();
        if (c[0]) c[0]->inOrder();
        cout << val << " ";
        if (c[1]) c[1]->inOrder();
        if (f) cout << "\n------------\n";
    }
};

pair<tnode*,tnode*> split(tnode* t, int v) { // >= v goes to the right
    if (!t) return {t,t};

    t->propogate();
    tnode* T = t->copy();

    if (v <= T->val) {
        auto p = split(T->c[0], v);
        T->c[0] = p.s; T->recalc();
        return {p.f, T};
    } else {
        auto p = split(T->c[1], v);
        T->c[1] = p.f; T->recalc();
        return {T, p.s};
    }
}

tnode* merge(tnode* l, tnode* r) {
    if (!l) return r;
    if (!r) return l;

    l->propogate(), r->propogate();
    if (l->pri > r->pri) {
        tnode* L = l->copy();
        L->c[1] = merge(L->c[1],r);
        L->recalc();
        return L;
    } else {
        tnode* R = r->copy();
        R->c[0] = merge(l,R->c[0]);
        R->recalc();
        return R;
    }
}

tnode* ins(tnode* x, int v) { // insert value v
    auto a = split(x,v);
    return merge(merge(a.f, new tnode(v)),a.s);
}

tnode* del(tnode* x, int v) { // delete all values equal to v
    auto a = split(x,v);
    auto b = split(a.s,v+1);
    return merge(a.f,b.s);
}

tnode *root, *root1;

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

    root = ins(root,1);
    root = ins(root,9);
    root = ins(root,3);

    root1 = root;
    root1->inOrder(1);

    root = ins(root,7);
    root = ins(root,4);
    root = del(root,9);

    root->inOrder(1);
    root1->inOrder(1);
    cout << root->sz << " " << root1->sz << "\n";
}
```

3. Flows

3.1. (5) Dinic

```
// source: GeeksForGeeks
```

```
const int SZ = 1000;

struct Edge {
    int v, flow, C, rev;
};

struct Dinic {
    int level[SZ], start[SZ];
    vector<Edge> adj[SZ];

    void addEdge(int u, int v, int C) {
        Edge a{v, 0, C, (int)adj[v].size()};
        Edge b{u, 0, 0, (int)adj[u].size()};
        adj[u].pb(a);
        adj[v].pb(b);
    }

    bool BFS(int s, int t) {
        FOR(i,SZ) level[i] = -1;
        level[s] = 0;

        queue<int> q; q.push(s);
        while (!q.empty()) {
            int u = q.front(); q.pop();
            for (auto e: adj[u])
                if (level[e.v] < 0 && e.flow < e.C) {
                    level[e.v] = level[u] + 1;
                    q.push(e.v);
                }
        }

        return level[t] >= 0;
    }

    int sendFlow(int u, int flow, int t) {
        if (u == t) return flow;

        for ( ; start[u] < adj[u].size(); start[u] ++) {
            Edge &e = adj[u][start[u]];

            if (level[e.v] == level[u]+1 && e.flow < e.C) {
                int curr_flow = min(flow, e.C - e.flow);
                int temp_flow = sendFlow(e.v, curr_flow, t);

                if (temp_flow > 0) {
                    e.flow += temp_flow;
                    adj[e.v][e.rev].flow -= temp_flow;
                    return temp_flow;
                }
            }
        }

        return 0;
    }

    int DinicMaxflow(int s, int t) {
        if (s == t) return -1;
        int total = 0;

        while (BFS(s, t)) {
            FOR(i,SZ) start[i] = 0;
            while (int flow = sendFlow(s, INT_MAX, t)) total += flow;
        }

        return total;
    }
};

Dinic D;

int main() {
    D.addEdge(0, 1, 16 );
    D.addEdge(0, 2, 13 );
    D.addEdge(1, 2, 10 );
    D.addEdge(1, 3, 12 );
    D.addEdge(2, 1, 4 );
    D.addEdge(2, 4, 14);
    D.addEdge(3, 2, 9 );
    D.addEdge(3, 5, 20 );
    D.addEdge(4, 3, 7 );
    D.addEdge(4, 5, 4);

    cout << "Maximum flow " << D.DinicMaxflow(0, 5);
}
```

3.2. (5) MinCostFlow

```
// Source: GeeksForGeeks
```

```
struct Edge {
    int v, flow, C, rev, cost;
};

template<int SZ> struct mcf {
    pii pre[SZ];
    int cost[SZ], num[SZ], SC, SNC;
    ll flo, ans, ccost;
    vector<Edge> adj[SZ];

    void addEdge(int u, int v, int C, int cost) {
        Edge a{v, 0, C, (int)adj[v].size(), cost};
        Edge b{u, 0, 0, (int)adj[u].size(), -cost};
        adj[u].pb(a), adj[v].pb(b);
    }

    void reweight() {
        FOR(i,SZ) {
            for (auto& p: adj[i]) p.cost += cost[i]-cost[p.v];
        }
    }

    bool spfa() {
        FOR(i,SZ) cost[i] = MOD, num[i] = 0;
        cost[SC] = 0, num[SC] = MOD;
        priority_queue<pii,vector<pii>,greater<pii>> todo;
            todo.push({0,SC});

        while (todo.size()) {
            pii x = todo.top(); todo.pop();
            if (x.f > cost[x.s]) continue;
            for (auto a: adj[x.s]) if (x.f+a.cost < cost[a.v] && a.flow <
                a.C) {
                pre[a.v] = {x.s,a.rev};
                cost[a.v] = x.f+a.cost;
                num[a.v] = min(a.C-a.flow,num[x.s]);
                todo.push({cost[a.v],a.v});
            }
        }

        ccost += cost[SNC];
        return num[SNC] > 0;
    }

    void backtrack() {
        flo += num[SNC], ans += (ll)num[SNC]*ccost;
        for (int x = SNC; x != SC; x = pre[x].f) {
            adj[x][pre[x].s].flow -= num[SNC];
            int t = adj[x][pre[x].s].rev;
            adj[pre[x].f][t].flow += num[SNC];
        }
    }

    pii mincostflow(int sc, int snc) {
        SC = sc, SNC = snc;
        flo = ans = ccost = 0;

        spfa();
        while (1) {
            reweight();
            if (!spfa()) return {flo,ans};
            backtrack();
        }
    }
};

mcf<100> m;

int main() {
    m.addEdge(0, 1, 16, 5);
    m.addEdge(1, 2, 13, 7);
    m.addEdge(1, 2, 13, 8);

    pii x = m.mincostflow(0,2);
    cout << x.f << " " << x.s;
}
```

4. Geometry

4.1. (3) Pair Operators

```
template<class T> pair<T,T> operator+(const pair<T,T>& l, const
    pair<T,T>& r) {
    return {l.f+r.f,l.s+r.s};
}
```

```
template<class T> pair<T,T> operator-(const pair<T,T>& l, const
    pair<T,T>& r) {
    return {l.f-r.f,l.s-r.s};
}

template<class T> pair<T,T> operator*(const pair<T,T>& l, T r) {
    return {l.f*r,l.s*r};
}

template<class T> pair<T,T> operator/(const pair<T,T>& l, T r) {
    return {l.f/r,l.s/r};
}

template<class T> double mag(pair<T,T> p) {
    return sqrt(p.f*p.f+p.s*p.s);
}

template<class T> pair<T,T> operator*(const pair<T,T>& l, const
    pair<T,T>& r) {
    // l.f+l.s*i, r.f+r.s*i
    return {l.f*r.f-l.s*r.s,l.s*r.f+l.f*r.s};
}

template<class T> pair<T,T> operator/(const pair<T,T>& l, const
    pair<T,T>& r) {
    // l.f+l.s*i, r.f+r.s*i
    pair<T,T> z = {r.f/(r.f*r.f+r.s*r.s),-r.s/(r.f*r.f+r.s*r.s)};
    return l*z;
}

template<class T> double area(pair<T,T> a, pair<T,T> b, pair<T,T> c) {
    b = b-a, c = c-a;
    return (b.f*c.s-b.s*c.f)/2;
}

template<class T> double dist(pair<T,T> l, pair<T,T> r) {
    return mag(r-l);
}

template<class T> double dist(pair<T,T> o, pair<T,T> x, pair<T,T> d) { //
    signed distance
    return 2*area(o,x,x+d)/mag(d);
}
```

4.2. (4) Closest Pair

```
// https://open.kattis.com/problems/closestpair2
// Nlog^2N

pair<double,pair<pdd,pdd>> MN = {INF,{{0,0},{0,0}}};

int n;

bool cmp(pdd a, pdd b) {
    return a.s < b.s;
}

double dist(pdd a, pdd b) {
    b.f -= a.f, b.s -= a.s;
    return sqrt(b.f*b.f+b.s*b.s);
}

pair<double,pair<pdd,pdd>> strip(vector<pdd> v, double di) {
    pair<double,pair<pdd,pdd>> ans = MN;
    FOR(i,v.size()) FOR(j,i+1,v.size()) {
        if (v[i].s+di <= v[j].s) break;
        ans = min(ans,{dist(v[i],v[j]),{v[i],v[j]}});
    }
    return ans;
}

pair<double,pair<pdd,pdd>> bes (vector<pdd> v) {
    if (v.size() == 1) return MN;
    int M = v.size()/2;
    vector<pdd> v1(v.begin(),v.begin()+M), v2(v.begin()+M,v.end());
    auto a = bes(v1), b = bes(v2);
    double di = min(a.f,b.f);

    vector<pdd> V;
    FOR(i,v.size()) if (v[i].f > v[M].f-di && v[i].f < v[M].f+di)
        V.pb(v[i]);
    sort(V.begin(),V.end(),cmp);

    auto z = strip(V,di);
    return min(min(a,b),z);
}

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

```
	cout << fixed << setprecision(2);
	while (cin >> n) {
		if (n == 0) break;
		vector<pdd> v(n);
		FOR(i,n) cin >> v[i].f >> v[i].s;
		sort(v.begin(),v.end());
		auto a = bes(v);
		cout << a.s.f.f << " " << a.s.f.s << " " << a.s.s.f << " " <<
			a.s.s.s << "\n";
	}
}
```

4.3. (4) Convex Hull

```
/**
* Source: Wikibooks
* Task: https://open.kattis.com/problems/convexhull
*/

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

vector<pii> convex_hull(vector<pii> P) {
	sort(P.begin(),P.end()); P.erase(unique(P.begin(),P.end()),P.end());
	if (P.size() == 1) return P;

	int n = P.size();

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

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

	bot.insert(bot.end(),up.begin(),up.end());
	return bot;
}

int main() {
	int n;
	while (cin >> n) {
		if (n == 0) break;
		vector<pii> P(n); FOR(i,n) cin >> P[i].f >> P[i].s;
		vector<pii> hull = convex_hull(P);

		cout << hull.size() << "\n";
		for (auto a: hull) cout << a.f << " " << a.s << "\n";
	}
}
```

4.4. (4) LineContainer

```
/**
* Source: KACTL
* Unused
*/

bool Q;
struct Line {
	mutable ll k, m, p; // slope, y-intercept, last optimal x
	bool operator<(const Line& o) const {
		return Q ? p < o.p : k < o.k;
	}
};

struct LineContainer : multiset<Line> {
	const ll inf = LLONG_MAX;
	ll div(ll a, ll b) { // floored division
		if (b < 0) a *= -1, b *= -1;
		if (a >= 0) return a/b;
		return -((-a+b-1)/b);
	}

	// updates x->p, determines if y is unneeded
	bool isect(iterator x, iterator y) {
```

```
            if (y == end()) { x->p = inf; return 0; }
            if (x->k == y->k) x->p = x->m > y->m ? inf : -inf;
            else x->p = div(y->m - x->m, x->k - y->k);
            return x->p >= y->p;
        }

        void add(ll k, ll m) {
            auto z = insert({k, m, 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());
            Q = 1; auto l = *lb({0,0,x}); Q = 0;
            return l.k * x + l.m;
        }
};

int main() {

}
```

4.5. (4) MaxCollinear

```
// https://open.kattis.com/problems/maxcolinear

int n, mx, ans;
map<pair<pii,int>,int> m;
pii p[1000];

pair<pii,int> getline(pii a, pii b) {
    pii z = {b.f-a.f,b.s-a.s};
    swap(z.f,z.s); z.f *= -1;
    int g = __gcd(z.f,z.s); z.f /= g, z.s /= g;
    if (z.f < 0 || (z.f == 0 && z.s < 0)) z.f *= -1, z.s *= -1;
    return {z,z.f*a.f+z.s*a.s};
}

void solve() {
    mx = ans = 0; m.clear();
    FOR(i,n) cin >> p[i].f >> p[i].s;
    FOR(i,n) FOR(j,i+1,n) m[getline(p[i],p[j])] ++;

    for (auto a: m) mx = max(mx,a.s);
    FOR(i,1,n+1) if (i*(i-1)/2 <= mx) ans = i;
    cout << ans << "\n";
}

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        while (cin >> n) {
            if (n == 0) break;
            solve();
        }
}
```

4.6. (4) Point in Polygon

```
// https://open.kattis.com/problems/pointinpolygon

int n,m;
pii p[1000];

int area(pii x, pii y, pii z) {
    return (y.f-x.f)*(z.s-x.s)-(y.s-x.s)*(z.f-x.f);
}

bool on(pii x, pii y, pii z) {
    if (area(x,y,z) != 0) return 0;
    return min(x,y) <= z && z <= max(x,y);
}

double get(pii x, pii y, int z) {
    return double((z-x.s)*y.f+(y.s-z)*x.f)/(y.s-x.s);
}

void test(pii z) {
    int ans = 0;
    FOR(i,n) {
        pii x = p[i], y = p[(i+1)%n];
        if (on(x,y,z)) {
            cout << "on\n";
            return;
```

```
        }
        if (x.s > y.s) swap(x,y);
        if (x.s <= z.s && y.s > z.s) {
            double t = get(x,y,z.s);
            if (t > z.f) ans++;
        }
    }
    if (ans % 2 == 1) cout << "in\n";
    else cout << "out\n";
}

void solve() {
    FOR(i,n) cin >> p[i].f >> p[i].s;
    cin >> m;
    FOR(i,m) {
        pii z; cin >> z.f >> z.s;
        test(z);
    }
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    while (cin >> n) {
        if (n == 0) break;
        solve();
    }
}
```

4.7. (4) Polygon Area

```
// https://open.kattis.com/problems/polygonarea

int n;

double area(vector<pii> v) {
    double x = 0;
    FOR(i,v.size()) {
        x += v[i].f*v[(i+1)%v.size()].s;
        x -= v[(i+1)%v.size()].f*v[i].s;
    }
    return x/2;
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    cout << fixed << setprecision(1);
    while (cin >> n) {
        if (n == 0) return 0;
        vector<pii> v(n); FOR(i,n) cin >> v[i].f >> v[i].s;
        double tmp = area(v);
        if (tmp < 0) cout << "CW ";
        else cout << "CCW ";
        cout << abs(tmp) << "\n";
    }
}
```

4.8. (5) LiChao Segment Tree

```
/**
* Source: http://codeforces.com/blog/entry/51275?#comment-351413
* Unused
*/

const int N = 100000 + 5;

int n, m;
int vis[N << 1];
char op[100];

struct line {
    double k, b;
    line(double _k = 0, double _b = 0) { k = _k; b = _b; }
    double get(double x) { return k * x + b; }
} c[N << 1];

void modify(int x, int l, int r, line v) {
    if (!vis[x]) { vis[x] = 1, c[x] = v; return; }
    if (c[x].get(l) > v.get(l) && c[x].get(r) > v.get(r)) return;
    if (c[x].get(l) < v.get(l) && c[x].get(r) < v.get(r)) { c[x] = v;
        return;}
    int m = (l + r) >> 1;
    if (c[x].get(l) < v.get(l)) swap(c[x], v);
    if (c[x].get(m) > v.get(m)) modify(x<<1|1, m + 1, r, v);
    else {swap(c[x], v); modify(x<<1, l, m, v);}
}
```

```
double get(int x, int l, int r, int pos) {
    if (l == r) return c[x].get(l);
    int m = (l + r) >> 1; double ans = c[x].get(pos);
    if (pos <= m) ans = max(ans, get(x<<1, l, m, pos));
    else ans = max(ans, get(x<<1|1, m + 1, r, pos));
    return ans;
}

int main() {
    cin >> n;
    FOR(i,n) {
        cin >> op;
        if (op[0] == 'Q') {
            int x; cin >> x;
            cout << get(1, 1, n, x) << "\n";
        } else {
            double k, b; cin >> b >> k;
            line l = line(k, b);
            modify(1, 1, n, l);
        }
    }
}
```

4.9. (5) Line Segment Intersection

```
/**
* Source: https://open.kattis.com/problems/segmentintersection
* If numbers are small enough, fractions are recommended.
*/

typedef pair<double,double> pdd;

pii A,B,C,D;

pdd operator*(int x, pdd y) {
    return {x*y.f,x*y.s};
}

pdd operator/(pdd y, int x) {
    return {y.f/x,y.s/x};
}

pdd operator+(pdd l, pdd r) {
    return {l.f+r.f,l.s+r.s};
}

int sgn(pii a, pii b, pii c) {
    return (b.s-a.s)*(c.f-a.f)-(b.f-a.f)*(c.s-a.s);
}

pdd get(pii a, pii b, pii c, pii d) {
    return
        (abs(sgn(a,b,c))*d+abs(sgn(a,b,d))*c)/(abs(sgn(a,b,c))+abs(sgn(a,b,d)));
}

void solve() {
    cin >> A.f >> A.s >> B.f >> B.s >> C.f >> C.s >> D.f >> D.s;
    if (A > B) swap(A,B);
    if (C > D) swap(C,D);
    int a1 = sgn(A,B,C), a2 = sgn(A,B,D);
    if (a1 > a2) swap(a1,a2);
    if (!(a1 <= 0 && a2 >= 0)) {
        cout << "none\n";
        return;
    }
    if (a1 == 0 && a2 == 0) {
        if (sgn(A,C,D) != 0) {
            cout << "none\n";
            return;
        }
        pii x1 = max(A,C), x2 = min(B,D);
        if (x1 > x2) cout << "none\n";
        else if (x1 == x2) cout << (double)x1.f << " " << (double)x1.s <<
            "\n";
        else cout << (double)x1.f << " " << (double)x1.s << " " <<
            (double)x2.f << " " << (double)x2.s << "\n";
        return;
    }
    pdd z = get(A,B,C,D);
    if (mp((double)A.f,(double)A.s) <= z && z <=
        mp((double)B.f,(double)B.s)) cout << z.f << " " << z.s << "\n";
    else cout << "none\n";
}

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        int n; cin >> n;
        cout << fixed << setprecision(2);
```

```
    FOR(i,n) solve();
}
```

4.10. (6) KD Tree

```
/**
* Source: KACTL
* Description: Supports nearest neighbor query in O(log n) assuming
    random distribution
* unused
*/

int t = 0, cur = 0;

struct point {
    ll d[2];
    point(ll x, ll y) {
        d[0] = x, d[1] = y;
    }
    point() {
        d[0] = 0, d[1] = 0;
    }
};

ll distance(point a, point b) {
    ll d = 0;
    FOR(i,2) d += (a.d[i]-b.d[i])*(a.d[i]-b.d[i]);
    return d;
}

bool comp(point a, point b) {
    return a.d[cur] < b.d[cur];
}

struct node {
    point* pt = NULL;
    point lo, hi;
    node* c[2];
    int ax = 0;

    ll dist(point p) {
        ll d = 0;
        FOR(i,2) {
            if (p.d[i] < lo.d[i]) d += (p.d[i]-lo.d[i])*(p.d[i]-lo.d[i]);
            else if (p.d[i] > hi.d[i]) d +=
                (p.d[i]-hi.d[i])*(p.d[i]-hi.d[i]);
        }
        return d;
    }

    node(int axis, point low, point high, vector<point> p) {
        lo = low, hi = high, ax = axis;
        if (p.size() > 1) {
            cur = ax;
            sort(p.begin(),p.end(),comp);

            int M = p.size()/2;
            while(M > 0 && p[M].d[ax] == p[M-1].d[ax]) M--;

            point lo1 = lo; lo1.d[ax] = p[M].d[ax];
            point hi1 = hi; hi1.d[ax] = p[M].d[ax]-1;

            if (M) c[0] = new
                node((ax+1)%2,lo,hi1,{p.begin(),p.begin()+M});
            c[1] = new node((ax+1)%2,lo1,hi,{p.begin()+M,p.end()});
        } else if (p.size() == 1) {
            pt = new point(p[0]);
        }
    }

    point get(point p) {
        if (pt) return *pt;
        if (!c[0]) return c[1]->get(p);

        int t = c[0]->dist(p) < c[1]->dist(p) ? 0 : 1;
        point z = c[t]->get(p);
        if (distance(p,z) <= c[t^1]->dist(p)) return z;

        point z1 = c[t^1]->get(p);
        if (distance(p,z) < distance(p,z1)) return z;
        return z1;
    }
};

node* root;

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

```
    vector<point> x;
    FOR(i,100000) x.pb(point(rand() % 1000000000, rand() %
        1000000000));

    root = new node(0,point(-MOD,-MOD),point(MOD,MOD),x);
    FOR(i,100000) {
        point y(rand() % 1000000000, rand() % 1000000000);
        cout << y.d[0] << " " << y.d[1] << " " << root->get(y).d[0] <<
            " " << root->get(y).d[1] << "\n";
    }
}
```

5. Graphs

5.1. (3) Topological Sort

```
int N,M, in[100001];
vi res, adj[100001];

void topo() {
    queue<int> todo;
    FOR(i,1,N+1) if (in[i] == 0) todo.push(i);
    while (todo.size()) {
        int x = todo.front(); todo.pop();
        res.pb(x);
        for (int i: adj[x]) {
            in[i] --;
            if (in[i] == 0) todo.push(i);
        }
    }
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    cin >> N >> M;
    FOR(i,M) {
        int x,y; cin >> x >> y;
        adj[x].pb(y), in[y] ++;
    }
    topo();
    for (int i: res) cout << i << " ";
}
```

5.2. (5) Biconnected Components

```
// http://www.geeksforgeeks.org/biconnected-components/

struct BCC {
    int V, ti = 0;
    vector<vi> adj;
    vi par, disc, low;
    vector<vector<pii>> fin;
    vector<pii> st;

    void init(int _V) {
        V = _V;
        par.resize(V), disc.resize(V), low.resize(V), adj.resize(V);
        FOR(i,V) par[i] = disc[i] = low[i] = -1;
    }
    void addEdge(int u, int v) {
        adj[u].pb(v), adj[v].pb(u);
    }

    void BCCutil(int u) {
        disc[u] = low[u] = ti++;
        int child = 0;

        for (int i: adj[u]) if (i != par[u]) {
            if (disc[i] == -1) {
                child ++; par[i] = u;
                st.pb({u,i});
                BCCutil(i);
                low[u] = min(low[u],low[i]);

                if ((disc[u] == 0 && child > 1) || (disc[u] != 0 &&
                    disc[u] <= low[i])) { // checks for articulation point
                    vector<pii> tmp;
                    while (st.back() != mp(u,i)) tmp.pb(st.back()),
                        st.pop_back();
                    tmp.pb(st.back()), st.pop_back();
                    fin.pb(tmp);
                }
            } else if (disc[i] < low[u]) {
                low[u] = disc[i];
                st.pb({u,i});
            }
        }
    }
```

```
    void bcc() {
        FOR(i,V) if (disc[i] == -1) {
            BCCutil(i);
            if (st.size()) fin.pb(st);
            st.clear();
        }
    }
};

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        BCC g; g.init(12);
        g.addEdge(0,1);
    g.addEdge(1,2);
    g.addEdge(1,3);
    g.addEdge(2,3);
    g.addEdge(2,4);
    g.addEdge(3,4);
    g.addEdge(1,5);
    g.addEdge(0,6);
    g.addEdge(5,6);
    g.addEdge(5,7);
    g.addEdge(5,8);
    g.addEdge(7,8);
    g.addEdge(8,9);
    g.addEdge(10,11);
    g.bcc();

    for (auto a: g.fin) {
        for (pii b: a) cout << b.f << " " << b.s << " | ";
        cout << "\n";
    }
}
```

5.3. (5) Kosaraju

```
const int MX = 100001;

struct scc {
    vi adj[MX], radj[MX], todo;
    int comp[MX], N, M;
    bool visit[MX];

    scc() {
        memset(comp,0,sizeof comp);
        memset(visit,0,sizeof visit);
    }

    void dfs(int v) {
        visit[v] = 1;
        for (int w: adj[v]) if (!visit[w]) dfs(w);
        todo.pb(v);
    }

    void dfs2(int v, int val) {
        comp[v] = val;
        for (int w: radj[v]) if (!comp[w]) dfs2(w,val);
    }

    void addEdge(int a, int b) {
                adj[a].pb(b);
                radj[b].pb(a);
    }

    void genSCC() {
        FOR(i,1,N+1) if (!visit[i]) dfs(i);
        reverse(todo.begin(),todo.end());
        for (int i: todo) if (!comp[i]) dfs2(i,i);
    }
};

scc S;

int main() {
        cin >> S.N >> S.M;
        FOR(i,S.M) {
                int a,b; cin >> a >> b;
                S.addEdge(a,b);
        }
        S.genSCC();
}
```

5.4. (6) Euler Tour

```
// https://open.kattis.com/problems/eulerianpath
```

```
// extra log factor

vi circuit;
multiset<int> adj[10000], adj1[10000];
int N,M, out[10000], in[10000];

void find_circuit(int x) { // directed graph, possible that resulting
    circuit is not valid
    while (adj[x].size()) {
        int j = *adj[x].begin(); adj[x].erase(adj[x].begin());
        find_circuit(j);
    }
    circuit.pb(x);
}

int a,b,start;

void solve() {
    FOR(i,N) {
        adj[i].clear(), adj1[i].clear();
        out[i] = in[i] = 0;
    }
    circuit.clear();
    FOR(i,M) {
        cin >> a >> b;
        adj[a].insert(b), adj1[a].insert(b);
        out[a] ++, in[b] ++;
    }
    start = a;
    FOR(i,N) if (out[i]-in[i] == 1) start = i;

    find_circuit(start);
    reverse(circuit.begin(),circuit.end());

    if (circuit.size() != M+1) {
        cout << "Impossible\n";
        return;
    }

    FOR(i,M) {
        if (adj1[circuit[i]].find(circuit[i+1]) == adj1[circuit[i]].end())
            {
            cout << "Impossible\n";
            return;
        }
        adj1[circuit[i]].erase(adj1[circuit[i]].find(circuit[i+1]));
    }
    FOR(i,M+1) cout << circuit[i] << " ";
    cout << "\n";
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    while (cin >> N >> M) {
        if (N+M == 0) break;
        solve();
    }
}
```

5.5. Shortest Path

5.5.1. (3) Bellman-Ford

```
/**
* Source: https://open.kattis.com/problems/shortestpath3
* Useful with linear programming
*/

const ll INF = 1e18;

int n,m,q,s,bad[1000];
vector<pair<pii,int>> edge;
ll dist[1000];

void solve() {
    edge.clear();
    FOR(i,n) dist[i] = INF, bad[i] = 0;
    dist[s] = 0;
    FOR(i,m) {
        int u,v,w; cin >> u >> v >> w;
        edge.pb({{u,v},w});
    }
    FOR(i,n) for (auto a: edge) if (dist[a.f.f] < INF) dist[a.f.s] =
        min(dist[a.f.s], dist[a.f.f]+a.s);
    for (auto a: edge) if (dist[a.f.f] < INF) if (dist[a.f.s] >
        dist[a.f.f]+a.s) bad[a.f.s] = 1;
    FOR(i,n) for (auto a: edge) if (bad[a.f.f]) bad[a.f.s] = 1;
```

```
    FOR(i,q) {
        int x; cin >> x;
        if (bad[x]) cout << "-Infinity\n";
        else if (dist[x] == INF) cout << "Impossible\n";
        else cout << dist[x] << "\n";
    }
    cout << "\n";
}
```

5.5.2. (3) Dijkstra

```
template<int SZ> struct Dijkstra {
    int dist[SZ];
    vector<pii> adj[SZ];
    priority_queue<pii,vector<pii>,greater<pii>> q;

    void gen() {
        fill_n(dist,SZ,MOD); dist[0] = 0;

        q.push({0,0});
        while (q.size()) {
               pii x = q.top(); q.pop();
               if (dist[x.s] < x.f) continue;
               for (pii y: adj[x.s]) if (x.f+y.s < dist[y.f]) {
                      dist[y.f] = x.f+y.s;
                      q.push({dist[y.f],y.f});
               }
        }
    }
};

Dijkstra<100> D;

int main() {
       FOR(i,100) FOR(j,100) if (rand() % 10 == 0) D.adj[i].pb({j,rand()
           % 10+1});
       D.gen();
       FOR(i,100) cout << D.dist[i] << "\n";
}
```

5.5.3. (3) Floyd-Warshall

```
/**
* Source: https://open.kattis.com/problems/allpairspath
*/

const ll INF = 1e18;

int n,m,q; // vertices, edges, queries
ll dist[150][150], bad[150][150];

void solve() {
    FOR(i,n) FOR(j,n) dist[i][j] = INF, bad[i][j] = 0;
    FOR(i,n) dist[i][i] = 0;
    FOR(i,m) {
        int u,v,w; cin >> u >> v >> w;
        dist[u][v] = min(dist[u][v],(ll)w);
    }
    FOR(k,n) FOR(i,n) FOR(j,n) if (dist[i][k] != INF && dist[k][j] != INF)
        dist[i][j] = min(dist[i][j],dist[i][k]+dist[k][j]);

    FOR(k,n) FOR(i,n) FOR(j,n) if (dist[i][k] != INF && dist[k][j] != INF)
        if (dist[i][j] > dist[i][k]+dist[k][j])
            bad[i][j] = 1;

    FOR(k,n) FOR(i,n) FOR(j,n) {
        if (dist[i][k] < INF && bad[k][j]) bad[i][j] = 1;
        if (bad[i][k] && dist[k][j] < INF) bad[i][j] = 1;
    }

    FOR(i,q) {
        int u,v; cin >> u >> v;
        if (bad[u][v]) cout << "-Infinity\n";
        else if (dist[u][v] == INF) cout << "Impossible\n";
        else cout << dist[u][v] << "\n";
    }
    cout << "\n";
}
```

6. Math

6.1. (5) Chinese Remainder Theorem

```
// https://open.kattis.com/problems/generalchineseremainder
```

```
ll n,m,a,b;
map<ll,pii> M;
bool bad;

ll inv(ll a, ll b) { // 0 < a < b, gcd(a,b) = 1
    a %= b;
    if (a <= 1) return a;
    ll i = inv(b%a,a);
    ll tmp = -((b/a)*i+((b%a)*i)/a) % b;
    while (tmp < 0) tmp += b;
    return tmp;
}

ll naive(ll n, ll m, ll a, ll b) {
    ll x = (a-b)*inv(m,n) % n;
    ll ans = (m*x+b) % (m*n);
    while (ans < 0) ans += (m*n);
    return ans;
}

void process(ll a, ll n) {
    vector<pii> z;
    for (int i = 2; i*i <= n; ++i) if (n % i == 0) {
        int co = 0;
        while (n % i == 0) n /= i, co++;
        z.pb({i,co});
    }
    if (n != 1) z.pb({n,1});
    for (auto A: z) {
        if (M.count(A.f)) {
            pii p1 = M[A.f];
            pii p2 = {A.s,a%(ll)pow(A.f,A.s)};
            if (p1 > p2) swap(p1,p2);
            if (p2.s%(ll)pow(A.f,p1.f) != p1.s) bad = 1;
            M[A.f] = p2;
        } else M[A.f] = {A.s,a%(ll)pow(A.f,A.s)};
    }
}

ll po(ll b, ll p) {
    ll z = 1;
    FOR(i,p) z *= b;
    return z;
}
```

```
void solve() {
    bad = 0, M.clear();
    long long aa,nn,bb,mm; cin >> aa >> nn >> bb >> mm;
    a = aa, n = nn, b = bb, m = mm;
    process(a,n), process(b,m);
    if (bad) {
        cout << "no solution\n";
        return;
    }
    ll a1 = 0, a2 = 1;
    for (auto& x: M) {
        a1 = naive(a2,po(x.f,x.s.f),a1,x.s.s);
        a2 *= po(x.f,x.s.f);
    }
    cout << (long long)a1 << " " << (long long)a2 << "\n";
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    int T; cin >> T;
    FOR(i,T) solve();
}
```

6.2. (5) Combinations

```
template<int SZ> struct Combo {
    ll fac[SZ+1], ifac[SZ+1];

    Combo() {
        fac[0] = ifac[0] = 1;
        FOR(i,1,SZ+1) {
            fac[i] = i*fac[i-1] % MOD;
            ifac[i] = inv(fac[i]);
        }
    }

    ll po (ll b, ll p) {
        return !p?1:po(b*b%MOD,p/2)*(p&1?b:1)%MOD;
    }

    ll inv (ll b) { return po(b,MOD-2); }
```

```
    ll comb(ll a, ll b) {
        if (a < b) return 0;
        ll tmp = fac[a]*ifac[b] % MOD;
        tmp = tmp*ifac[a-b] % MOD;
        return tmp;
    }
};
```

6.3. (5) Eratosthenes' Sieve

```
// https://open.kattis.com/problems/primesieve

template<int SZ> struct Sieve {
    bitset<SZ+1> comp;
    Sieve() {
        for (int i = 2; i*i <= SZ; ++i) if (!comp[i]) {
            for (int j = i*i; j <= SZ; j += i) comp[j] = 1;
        }
    }
    bool isprime(int x) {
        if (x == 1) return 0;
        return !comp[x];
    }
};

int n,q,ans=0;

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    Sieve<100000000> s; cin >> n >> q;
    FOR(i,1,n+1) if (s.isprime(i)) ans ++;
    cout << ans << "\n";
    FOR(i,q) {
        int x; cin >> x;
        cout << s.isprime(x) << "\n";
    }
}
```

6.4. (5) General Modular Inverse

```
int inv(int a, int b) { // 0 < a < b, gcd(a,b) = 1
    if (a == 1) return 1;
    ll i = inv(b%a,a);
    ll tmp = -((b/a)*i+((b%a)*i)/a) % b;
    while (tmp < 0) tmp += b;
    return tmp;
}

int main() {
    ios_base::sync_with_stdio(0);cin.tie(0);
    cout << inv(25,43); // 31
}
```

6.5. (6) FFT, NTT

```
/**
* inspired by KACTL
* https://pastebin.com/3Tnj5mRu
*/

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

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

    namespace FFT {
        vcd fft(vcd& a) {
            int n = a.size(), x = get(n);
            vcd res, RES(n), roots(n);
            FOR(i,n) roots[i] = cd(cos(2*M_PI*i/n),sin(2*M_PI*i/n));

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

            return res;
```

```
    }

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

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

    vcd conv(vcd a, vcd b) {
        int s = sz(a)+sz(b)-1, L = get(s), n = 1<<L;
        if (s <= 0) return {};
        if (s <= 200) return brute(a,b);

        a.resize(n); a = fft(a);
        b.resize(n); b = fft(b);

        FOR(i,n) a[i] *= b[i];
        a = fft_rev(a);

        a.resize(s);
        return a;
    }
}

namespace NTT {
    const ll mod = (119 << 23) + 1, root = 3; // = 998244353
    // For p < 2^30 there is also e.g. (5 << 25, 3), (7 << 26, 3),
    // (479 << 21, 3) and (483 << 21, 5). The last two are > 10^9.

    ll modpow(ll b, ll p) { return
         !p?1:modpow(b*b%mod,p/2)*(p&1?b:1)%mod; }

    ll inv (ll b) { return modpow(b,mod-2); }

    vl ntt(vl& a) {
        int n = a.size(), x = get(n);
        vl res, RES(n), roots(n);
        roots[0] = 1, roots[1] = modpow(root,(mod-1)/n);
        FOR(i,2,n) roots[i] = roots[i-1]*roots[1] % mod;

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

        return res;
    }

    vl ntt_rev(vl& a) {
        vl res = ntt(a);
        ll in = inv(a.size());
        FOR(i,sz(res)) res[i] = res[i]*in % mod;
        reverse(res.begin() + 1, res.end());
        return res;
    }

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

    vl conv(vl a, vl b) {
        int s = sz(a)+sz(b)-1, L = get(s), n = 1<<L;
        if (s <= 0) return {};
        if (s <= 200) return brute(a,b);

        a.resize(n); a = ntt(a);
        b.resize(n); b = ntt(b);

        FOR(i,n) a[i] = a[i]*b[i] % mod;
        a = ntt_rev(a);

        a.resize(s);
        return a;
    }
  }
}
```

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

    vcd x = Poly::FFT::conv({1,2,3,4,5,6,7,8},{1,2,3,4,5,6,7,8});
    for (auto a: x) cout << a << "\n";
    cout << "\n";

    vl X = Poly::NTT::conv({1,2,3,4,5,6,7,8},{1,2,3,4,5,6,7,8});
    for (auto a: X) cout << a << "\n";
}
```

7. Strings

7.1. (3) Hashing

```
typedef pair<ll, ll> pll;

template<class T> pair<T,T> operator+(const pair<T,T>& l, const
    pair<T,T>& r) {
    return {(l.f+r.f)%MOD,(l.s+r.s)%MOD};
}

template<class T> pair<T,T> operator-(const pair<T,T>& l, const
    pair<T,T>& r) {
    return {(l.f-r.f+MOD)%MOD,(l.s-r.s+MOD)%MOD};
}

template<class T> pair<T,T> operator*(const pair<T,T>& l, const T& r) {
    return {l.f*r%MOD,l.s*r%MOD};
}

template<class T> pair<T,T> operator*(const pair<T,T>& l, const
    pair<T,T>& r) {
    return {l.f*r.f%MOD,l.s*r.s%MOD};
}

struct hsh {
    string S;
    vector<pll> po, ipo, cum;
    pll base = mp(948392576,573928192);

    ll modpow(ll b, ll p) {
        return !p?1:modpow(b*b%MOD,p/2)*(p&1?b:1)%MOD;
    }

    ll inv(ll x) {
        return modpow(x,MOD-2);
    }

    void gen(string _S) {
        S = _S;
        po.resize(sz(S)), ipo.resize(sz(S)), cum.resize(sz(S)+1);
        po[0] = ipo[0] = {1,1};
        FOR(i,1,sz(S)) {
            po[i] = po[i-1]*base;
            ipo[i] = {inv(po[i].f),inv(po[i].s)};
        }
        FOR(i,sz(S)) cum[i+1] = cum[i]+po[i]*(ll)(S[i]-'a'+1);
    }

    pll get(int l, int r) {
        return ipo[l]*(cum[r+1]-cum[l]);
    }
};

int lcp(hsh& a, hsh& b) {
    int lo = 0, hi = min(sz(a.S),sz(b.S));
    while (lo < hi) {
        int mid = (lo+hi+1)/2;
        if (a.get(0,mid-1) == b.get(0,mid-1)) lo = mid;
        else hi = mid-1;
    }
    return lo;
}

int main() {
    string _S = "abacaba";
    hsh h; h.gen(_S);
    FOR(i,sz(_S)) FOR(j,i,sz(_S)) cout << i << " " << j << " " <<
        h.get(i,j).f << " " << h.get(i,j).s << "\n";

    hsh H; H.gen("abadaba");
    cout << lcp(h,H);
}
```

7.2. (4) Bitset Trie

```
template<int MX> struct tri {
    int nex = 0, ans = 0;
    int trie[MX][2]; // easily changed to character

    tri() {
        memset(trie,0,sizeof trie);
    }

    void ins(int x) {
        int cur = 0;
        FORd(i,30) {
            int t = (x&(1<<i))>>i;
            if (!trie[cur][t]) trie[cur][t] = ++nex;
            cur = trie[cur][t];
        }
    }

    void test(int x) {
        int cur = 0;
        FORd(i,30) {
            int t = ((x&(1<<i))>>i) ^ 1;
            if (!trie[cur][t]) t ^= 1;
            cur = trie[cur][t];
            if (t) x ^= (1<<i);
        }
        ans = max(ans,x);
    }
};

int main() {

}
```

7.3. (5) Aho-Corasick

```
// Source: GeeksForGeeks
// also see https://ideone.com/0cMjZJ

string arr[200];
int val[200], states = 1;
queue<int> update;

const int MAXS = 201;
const int MAXC = 26;

int n, out[MAXS], f[MAXS], g[MAXS][MAXC];

int buildMatchingMachine() {
    memset(out, 0, sizeof out);
    memset(g, -1, sizeof g);

    FOR(i,n) {
        string word = arr[i];
        int currentState = 0;

        FOR(j,word.size()) {
            int ch = word[j] - 'a';
            if (g[currentState][ch] == -1) g[currentState][ch] = states++;
            currentState = g[currentState][ch];
        }

        out[currentState] += val[i];
    }

    FOR(ch,MAXC) if (g[0][ch] == -1) g[0][ch] = 0;
    memset(f, -1, sizeof f);
    queue<int> q;

    FOR(ch,MAXC)
        if (g[0][ch] != 0) {
            f[g[0][ch]] = 0;
            q.push(g[0][ch]);
        }

    while (q.size()) {
        int state = q.front();
        q.pop();

        FOR(ch,MAXC) {
            if (g[state][ch] != -1) {
                int failure = f[state];
                while (g[failure][ch] == -1) failure = f[failure];

                failure = g[failure][ch];
                f[g[state][ch]] = failure;

                out[g[state][ch]] += out[failure];
```

```
                q.push(g[state][ch]);
            }
        }
    }

    return states;
}

int findNextState(int currentState, char nextInput) {
    int answer = currentState;
    int ch = nextInput - 'a';

    while (g[answer][ch] == -1){
        update.push(answer);
        answer = f[answer];
    }
    if (update.size()){
        while (update.size()){
            int k = update.front(); update.pop();
            g[k][nextInput-'a'] = g[answer][ch]; //cache state
                transitions: often necessary if we don't want to
                explicitly compute all of them
        }
    }
    return g[answer][ch];
}

int main() {

}
```

7.4. (5) Manacher

```
// Source: http://codeforces.com/blog/entry/12143
// Calculates length of largest palindrome centered at each character of
    string

vi manacher(string s) {
    string s1 = "@";
    for (char c: s) s1 += c, s1 += "#";
    s1[s1.length()-1] = '&';
    vi ans(s1.length()-1);
    int lo = 0, hi = 0;
    FOR(i,1,s1.length()-1) {
        ans[i] = min(hi-i,ans[hi-i+lo]);
        while (s1[i-ans[i]-1] == s1[i+ans[i]+1]) ans[i] ++;
        if (i+ans[i] > hi) lo = i-ans[i], hi = i+ans[i];
    }

    ans.erase(ans.begin());
    FOR(i,ans.size()) if ((i&1) == (ans[i]&1)) ans[i] ++; // adjust
        lengths
    return ans;
}

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        vi a1 = manacher("abacaba");
        for (int i: a1) cout << i << " ";
        cout << "\n";

        vi a2 = manacher("aabbaaccaabbaa");
        for (int i: a2) cout << i << " ";
}
```

7.5. (5) Palindromic Tree

```
/**
* Source: http://codeforces.com/blog/entry/13959
* Unused
*/

const int maxn = 1e5, sigma = 26;

int s[maxn], len[maxn], link[maxn], to[maxn][sigma];

int n, last, sz;

void init() {
    s[n++] = -1;
    link[0] = 1;
    len[1] = -1;
    sz = 2;
}
```

```
int get_link(int v) {
    while(s[n-len[v]-2] != s[n-1]) v = link[v];
    return v;
}

void add_letter(int c) {
    s[n++] = c;
    last = get_link(last);
    if (!to[last][c]) {
        len[sz] = len[last]+2;
        link[sz] = to[get_link(link[last])][c];
        to[last][c] = sz++;
    }
    last = to[last][c];
}
```

7.6. (5) Z

```
// Source: http://codeforces.com/blog/entry/3107
// better than KMP?

vi z(string s) {
    int N = s.length(); s += '#';
    vi ans(N); ans[0] = N;
    while (s[1+ans[1]] == s[ans[1]]) ans[1] ++;

    int L = 1, R = ans[1];
    FOR(i,2,N) {
        if (i <= R) ans[i] = min(R-i+1,ans[i-L]);
        while (s[i+ans[i]] == s[ans[i]]) ans[i] ++;
        if (i+ans[i]-1 > R) L = i, R = i+ans[i]-1;
    }
    return ans;
}

vi get(string a, string b) { // find prefixes of a in b
    string s = a+"@"+b;
    vi t = z(s);
    return vi(t.begin()+a.length()+1,t.end());
}

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        vi x = z("abcababcabcaba");
        for (int i: x) cout << i << " ";
        cout << "\n";

        x = get("abcab","uwetrabcerabcab");
        for (int i: x) cout << i << " ";
}
```

7.7. (6) Booth

```
/**
* Source: Wikipeddia
* unused
*/

int least_rotation(string S) {
    S += S;
    vi f = vi(S.length(),-1);
    int k = 0;
    FOR(j,1,S.length()) {
        char sj = S[j];
        int i = f[j-k-1];
        while (i != -1 and sj != S[k+i+1]) {
            if (sj < S[k+i+1]) k = j-i-1;
            i = f[i];
        }
        if (sj != S[k+i+1]) {
            if (sj < S[k]) k = j;
            f[j-k] = -1;
        } else f[j-k] = i+1;
    }
    return k;
}

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        cout << least_rotation("cccaabbb");
}
```

7.8. (6) Suffix Array

```
/**
* Source: SuprDewd CP Course
* Task: https://open.kattis.com/problems/suffixsorting
*/

struct suffix_array {
    int N;
    vector<vi> P;
    vector<pair<pii,int>> L;
    vi idx;
    string str;

    suffix_array(string _str) {
        str = _str; N = str.length();
        P.pb(vi(N)); L.resize(N);
        FOR(i,N) P[0][i] = str[i];

        for (int stp = 1, cnt = 1; cnt < N; stp ++, cnt *= 2) {
            P.pb(vi(N));
            FOR(i,N) L[i] = {{P[stp-1][i],i+cnt < N ? P[stp-1][i+cnt] :
                -1},i};
            sort(L.begin(),L.end());
            FOR(i,N) {
                if (i && L[i].f == L[i-1].f) P[stp][L[i].s] =
                    P[stp][L[i-1].s];
                else P[stp][L[i].s] = i;
            }
        }

        idx.resize(N);
        FOR(i,P[P.size()-1].size()) idx[P[P.size()-1][i]] = i;
    }

    int lcp(int x, int y) {
        int res = 0;
        if (x == y) return N-x;
        for (int k = P.size() - 1; k >= 0 && x < N && y < N; k--) {
            if (P[k][x] == P[k][y]) {
                x += 1 << k;
                y += 1 << k;
                res += 1 << k;
            }
        }
        return res;
    }
};

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        string s;
        while (getline(cin,s)) {
            if (s[s.length()-1] == '\r') s.erase(s.end()-1);
            suffix_array sa = suffix_array(s);
            int z; cin >> z;
            FOR(i,z) {
                int x; cin >> x;
                cout << sa.idx[x] << " ";
            }
            cout << "\n";
            getline(cin,s);
        }
}
```

8. Trees

8.1. (3) DSU, Kruskal

```
// compute the minimum spanning tree in O(ElogE) time
// https://en.wikipedia.org/wiki/Kruskal%27s_algorithm

template<int SZ> struct DSU {
    int par[SZ], sz[SZ];
    DSU() {
        FOR(i,SZ) par[i] = i, sz[i] = 1;
    }

    int get(int x) { // path compression
        if (par[x] != x) par[x] = get(par[x]);
        return par[x];
    }

    bool unite(int x, int y) { // union-by-rank
        x = get(x), y = get(y);
        if (x == y) return 0;
        if (sz[x] < sz[y]) swap(x,y);
        sz[x] += sz[y], par[y] = x;
```

```
        return 1;
    }
};

int ans = 0;
vector<pair<int,pii>> edge;

DSU<100> D;

void kruskal() {
        sort(edge.begin(),edge.end());
        for (auto a: edge) if (D.unite(a.s.f,a.s.s)) ans += a.f;
}

int main() {
        FOR(i,100) FOR(j,i+1,100) if (rand() % 5 == 0) edge.pb({rand() %
            100+1,{i,j}});
        kruskal();
        cout << D.sz[D.get(5)] << " " << ans;
}
```

8.2. (4) Centroid Decomposition

```
const int MX = 100001;

int N, visit[MX], sub[MX], par[MX];
vi adj[MX];

void dfs (int no) {
    sub[no] = 1;
    for (int i: adj[no]) if (!visit[i] && i != par[no]) {
        par[i] = no;
        dfs(i);
        sub[no] += sub[i];
    }
}

int get_centroid(int x) {
    par[x] = 0;
    dfs(x);
    int sz = sub[x];
    while (1) {
        pii mx = {0,0};
        for (int i: adj[x]) if (!visit[i] && i != par[x]) mx =
            max(mx,{sub[i],i});
        if (mx.f*2 > sz) x = mx.s;
        else return x;
    }
}

void solve (int x) {
    x = get_centroid(x); visit[x] = 1;
    // do stuff
    cout << x << "\n";
    for (int i: adj[x]) if (!visit[i]) solve(i);
}

int main() {
        ios_base::sync_with_stdio(0);cin.tie(0);
        cin >> N;
        FOR(i,N-1) {
            int a,b; cin >> a >> b;
            adj[a].pb(b), adj[b].pb(a);
        }
        solve(1);
}
```

8.3. (4) HLD

```
/**
* Source: http://codeforces.com/blog/entry/22072
* Task: http://www.usaco.org/index.php?page=viewproblem2&cpid=102
*/

// insert LazySegTree Template

vector<vi> graph;

template <int V> struct HeavyLight { // sum queries, sum updates
    int parent[V], heavy[V], depth[V];
    int root[V], treePos[V];
    LazySegTree<V> tree;

    void init() {
        int n = graph.size();
        FOR(i,1,n+1) heavy[i] = -1;
```

```
        parent[1] = -1, depth[1] = 0;
        dfs(1);
        for (int i = 1, currentPos = 0; i <= n; ++i)
                        if (parent[i] == -1 || heavy[parent[i]] != i)
                                for (int j = i; j != -1; j = heavy[j]) {
                                        root[j] = i;
                                        treePos[j] = currentPos++;
                                }
    }

    int dfs(int v) {
        int size = 1, maxSubtree = 0;
        for (auto u : graph[v]) if (u != parent[v]) {
            parent[u] = v;
            depth[u] = depth[v] + 1;
            int subtree = dfs(u);
            if (subtree > maxSubtree) heavy[v] = u, maxSubtree = subtree;
            size += subtree;
        }
        return size;
    }

    template <class BinaryOperation>
    void processPath(int u, int v, BinaryOperation op) {
        for (; root[u] != root[v]; v = parent[root[v]]) {
            if (depth[root[u]] > depth[root[v]]) swap(u, v);
            op(treePos[root[v]], treePos[v]);
        }
        if (depth[u] > depth[v]) swap(u, v);
        op(treePos[u]+1, treePos[v]); // assumes values are stored in
            edges, not vertices
    }

    void modifyPath(int u, int v, int value) {
        processPath(u, v, [this, &value](int l, int r) { tree.upd(l, r,
            value); });
    }

    ll queryPath(int u, int v) {
        ll res = 0;
        processPath(u, v, [this, &res](int l, int r) { res += tree.qsum(l,
            r); });
        return res;
    }
};
```

```
HeavyLight<1<<17> H;
int N,M;

int main() {
        cin >> N >> M;
        graph.resize(N+1);
        FOR(i,N-1) {
            int a,b; cin >> a >> b;
            graph[a].pb(b), graph[b].pb(a);
        }
        H.init();
        FOR(i,M) {
            char c; int A,B;
            cin >> c >> A >> B;
            if (c == 'P') H.modifyPath(A,B,1);
            else cout << H.queryPath(A,B) << "\n";
        }
}
```

8.4. (4) LCA with Binary Jumps

```
const int MAXN = 100001, MAXK = 17;

int Q;

struct LCA {
    int V;
    vi edges[MAXN];
    int parK[MAXK][MAXN];
    int depth[MAXN];

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

    void dfs(int u, int prev){
        parK[0][u] = prev;
        depth[u] = depth[prev]+1;
        for (int v: edges[u]) if (v != prev) dfs(v, u);
    }

    void construct() {
```

```
        dfs(1, 0);
        FOR(k,1,MAXK) FOR(i,1,V+1)
            parK[k][i] = parK[k-1][parK[k-1][i]];
    }

    int lca(int u, int v){
        if (depth[u] < depth[v]) swap(u,v);

        FORd(k,MAXK) if (depth[u] >= depth[v]+(1<<k)) u = parK[k][u];
        FORd(k,MAXK) if (parK[k][u] != parK[k][v]) u = parK[k][u], v =
            parK[k][v];

        if(u != v) u = parK[0][u], v = parK[0][v];
        return u;
    }

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

LCA L;

int main(){
    cin >> L.V >> Q;
    FOR(i,L.V-1) {
        int u,v; cin >> u >> v;
        L.addEdge(u,v);
    }
    L.construct();

    FOR(i,Q) {
        int u,v; cin >> u >> v;
        cout << L.dist(u,v) << "\n";
    }
}
```

8.5. (4) LCA with RMQ

```
// Euler Tour LCA w/ O(1) query

const int MAXN = 100001, MAXK = 17;

int Q;

struct RMQ2 {
    vi edges[MAXN];
    pii rmq[MAXK][2*MAXN];
    int depth[MAXN], pos[MAXN];

    int N, nex=0;

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

    void dfs(int u, int prev){
        pos[u] = nex; depth[u] = depth[prev]+1;
        rmq[0][nex++] = {depth[u],u};
        for (int v: edges[u]) if (v != prev) {
            dfs(v, u);
            rmq[0][nex++] = {depth[u],u};
        }
    }

    void construct() {
        dfs(1, 0);
        FOR(k,1,MAXK) FOR(i,nex) if (i+(1<<(k-1)) < nex) rmq[k][i] =
            min(rmq[k-1][i],rmq[k-1][i+(1<<(k-1))]);
    }

    int lca(int u, int v){
        u = pos[u], v = pos[v];
        if (u > v) swap(u,v);
        int x = 31-__builtin_clz(v-u+1);
        return min(rmq[x][u],rmq[x][v-(1<<x)+1]).s;
    }

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

RMQ2 R;

int main(){
    cin >> R.N >> Q;
    FOR(i,R.N-1) {
```

```
        int u,v; cin >> u >> v;
        R.addEdge(u,v);
    }
    R.construct();

    FOR(i,Q) {
        int u,v; cin >> u >> v;
        cout << R.dist(u,v) << "\n";
    }
}
```