

ACM ICPC TEAM REFERENCE 2010 WORLD FINALS

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1. CONFIGURATION FILES AND SCRIPTS

1.1. **.emacs**. Hash: b1040cede72bb06f9b3197eba2d833f5

```
(global-font-lock-mode t)
(setq transient-mark-mode t)

(global-set-key [f5] 'cxx-compile)
(defun cxx-compile()
  (interactive)
  (save-buffer)
```

```
(compile (concat "g++-g_-O2-o_" (file-name-sans-extension buffer-file-name)
  "_" buffer-file-name))
)

(add-hook 'c++-mode-hook (lambda () (c-set-style "stroustrup")
  (flymake-mode t)))
```

1.2. **Makefile**. Hash: 7381d22266f4ef5a9a601b80a76a956c

```
check-syntax:
```

```
g++ -Wall -fsyntax-only $(CHK_SOURCES)
```

1.3. **.vimrc**. Hash: da63747b3e94a58450094526d21a9e41

```
syn on
set nocp number ai si ts=4 sts=4 sw=4
```

```
ab #i #include
```

1.4. **Hash generator**. Hash: 0d22aecd779fc370b30a2c628aff517c

```
#!/bin/sh
```

```
sed ':a;N;$!ba;s/[_\n\t]//g' | md5sum | cut -d'_' -f1
```

1.5. Solution template. Hash: 220ea9d23d25447636bd67aeaf899fee

```
#include <algorithm>
#include <cassert>
#include <cmath>
#include <cstdio>
#include <cstdlib>
#include <cstring>
#include <ctime>
#include <iostream>
#include <map>
#include <queue>
```

```
#include <set>
#include <sstream>
#include <string>
#include <utility>
#include <vector>

using namespace std;

int main() {
}
```

2. GRAPH ALGORITHMS

2.1. Tarjan's SCC algorithm. Hash: 16e646ee186fcff5ed68116af46b0820

```
int lowest[MAXV], num[MAXV], visited[MAXV], comp[MAXV];
int prev_edge[MAXE], last_edge[MAXV], adj[MAXE], nedges;
int cur_num, cur_comp;
stack<int> visiting;

int t_init() {
    memset(last_edge, -1, sizeof last_edge);
    nedges = 0;
}

void t_edge(int v, int w) {
    prev_edge[nedges] = last_edge[v];
    adj[nedges] = w;
    last_edge[v] = nedges++;
}

int tarjan_dfs(int v) {
    lowest[v] = num[v] = cur_num++;
    visiting.push(v);

    visited[v] = 1;
    for(int i = last_edge[v]; i != -1; i = prev_edge[i]) {
        int w = adj[i];
        if(visited[w] == 0) lowest[v] = min(lowest[v], tarjan_dfs(w));
        else if(visited[w] == 1) lowest[v] = min(lowest[v], num[w]);
    }
}
```

```
    }

    if(lowest[v] == num[v]) {
        int last = -1;
        while(last != v) {
            comp[last = visiting.top()] = cur_comp;
            visited[last] = 2;
            visiting.pop();
        }
        ++cur_comp;
    }

    return lowest[v];
}

void tarjan_scc(int num_v = MAXV) {
    visiting = stack<int>();
    memset(visited, 0, sizeof visited);
    cur_num = cur_comp = 0;

    for(int i = 0; i < num_v; ++i)
        if(!visited[i])
            tarjan_dfs(i);
}
```

2.2. Dinic's maximum flow algorithm. Hash: 4dd537effe7e233681c099912397839a

```

int last_edge[MAXV], cur_edge[MAXV], dist[MAXV];
int prev_edge[MAXE], cap[MAXE], flow[MAXE], adj[MAXE];
int nedges;

void d_init() {
    nedges = 0;
    memset(last_edge, -1, sizeof last_edge);
}

void d_edge(int v, int w, int capacity, bool r = false) {
    prev_edge[nedges] = last_edge[v];
    cap[nedges] = capacity;
    adj[nedges] = w;
    flow[nedges] = 0;
    last_edge[v] = nedges++;
}

if(!r) d_edge(w, v, 0, true);
}

bool d_auxflow(int source, int sink) {
    queue<int> q;
    q.push(source);

    memset(dist, -1, sizeof dist);
    dist[source] = 0;
    memcpy(cur_edge, last_edge, sizeof last_edge);

    while(!q.empty()) {
        int v = q.front(); q.pop();
        for(int i = last_edge[v]; i != -1; i = prev_edge[i]) {
            if(cap[i] - flow[i] == 0) continue;

            if(dist[adj[i]] == -1) {
                dist[adj[i]] = dist[v] + 1;
                q.push(adj[i]);
            }

            if(adj[i] == sink) return true;
        }
    }
}

```

```

    }
}

return false;
}

inline int rev(int i) { return i ^ 1; }

int d_augmenting(int v, int sink, int c) {
    if(v == sink) return c;

    for(int& i = cur_edge[v]; i != -1; i = prev_edge[i]) {
        if(cap[i] - flow[i] == 0 || dist[adj[i]] != dist[v] + 1)
            continue;

        int val;
        if(val = d_augmenting(adj[i], sink, min(c, cap[i] - flow[i]))) {
            flow[i] += val;
            flow[rev(i)] -= val;
            return val;
        }
    }

    return 0;
}

int dinic(int source, int sink) {
    int ret = 0;
    while(d_auxflow(source, sink)) {
        int flow;
        while(flow = d_augmenting(source, sink, 0x3f3f3f3f))
            ret += flow;
    }

    return ret;
}

```

2.3. Successive shortest paths mincost maxflow algorithm. Hash: 1899233cb68a8d5f6e280654146e1747

```

int dist[MAXV], last_edge[MAXV], d_visited[MAXV], bg_prev[MAXV], pot[MAXV],
    capres[MAXV];

```

```

int prev_edge[MAXE], adj[MAXE], cap[MAXE], cost[MAXE], flow[MAXE];

```

```

int nedges;
priority_queue<pair<int, int> > d_q;

inline void bg_edge(int v, int w, int capacity, int cst, bool r = false) {
    prev_edge[nedges] = last_edge[v];
    adj[nedges] = w;
    cap[nedges] = capacity;
    flow[nedges] = 0;
    cost[nedges] = cst;
    last_edge[v] = nedges++;

    if(!r) bg_edge(w, v, 0, -cst, true);
}

inline int rev(int i) { return i ^ 1; }
inline int from(int i) { return adj[rev(i)]; }

inline void bg_init() {
    nedges = 0;
    memset(last_edge, -1, sizeof last_edge);
    memset(pot, 0, sizeof pot);
}

void bg_dijkstra(int s, int num_nodes = MAXV) {
    memset(dist, 0x3f, sizeof dist);
    memset(d_visited, 0, sizeof d_visited);
    d_q.push(make_pair(dist[s] = 0, s));
    capres[s] = 0x3f3f3f3f;

    while(!d_q.empty()) {
        int v = d_q.top().second; d_q.pop();
        if(d_visited[v]) continue; d_visited[v] = true;

        for(int i = last_edge[v]; i != -1; i = prev_edge[i]) {

```

```

            if(cap[i] - flow[i] == 0) continue;
            int w = adj[i], new_dist = dist[v] + cost[i] + pot[v] - pot[w];

            if(new_dist < dist[w]) {
                d_q.push(make_pair(-(dist[w] = new_dist), w));
                bg_prev[w] = rev(i);
                capres[w] = min(capres[v], cap[i] - flow[i]);
            }
        }
    }

pair<int, int> busacker_gowen(int src, int sink, int num_nodes = MAXV) {
    int ret_flow = 0, ret_cost = 0;

    bg_dijkstra(src, num_nodes);
    while(dist[sink] < 0x3f3f3f3f) {
        int cur = sink;
        while(cur != src) {
            flow[bg_prev[cur]] -= capres[sink];
            flow[rev(bg_prev[cur])] += capres[sink];
            ret_cost += cost[rev(bg_prev[cur])] * capres[sink];
            cur = adj[bg_prev[cur]];
        }
        ret_flow += capres[sink];

        for(int i = 0; i < MAXV; ++i)
            pot[i] = min(pot[i] + dist[i], 0x3f3f3f3f);

        bg_dijkstra(src, num_nodes);
    }
    return make_pair(ret_flow, ret_cost);
}

```

2.4. Gabow's general matching algorithm (WRONG). Hash: a173c8d78c8dfd97bfacfc98e6ef92ea

```

int prev_edge[MAXE], v[MAXE], w[MAXE], last_edge[MAXV];
int type[MAXV], label[MAXV], first[MAXV], mate[MAXV], nedges;
bool g_flag[MAXV], g_souter[MAXV];

void g_init() {
    nedges = 0;
    memset(last_edge, -1, sizeof last_edge);
}

```

```

void g_edge(int a, int b) {
    prev_edge[nedges] = last_edge[a];
    v[nedges] = a;
    w[nedges] = b;
    last_edge[a] = nedges++;

    prev_edge[nedges] = last_edge[b];
}

```

```

    v[nedges] = b;
    w[nedges] = a;
    last_edge[b] = nedges++;
}

void g_label(int v, int join, int edge, queue<int>& outer) {
    if(v == join) return;
    if(label[v] == -1) outer.push(v);

    label[v] = edge;
    type[v] = 1;
    first[v] = join;

    g_label(first[label[mate[v]]], join, edge, outer);
}

void g_augment(int _v, int _w) {
    int t = mate[_v];
    mate[_v] = _w;

    if(mate[t] != _v) return;
    if(label[_v] == -1) return;

    if(type[_v] == 0) {
        mate[t] = label[_v];
        g_augment(label[_v], t);
    }
    else if(type[_v] == 1) {
        g_augment(v[label[_v]], w[label[_v]]);
        g_augment(w[label[_v]], v[label[_v]]);
    }
}

int gabow(int n) {
    memset(mate, -1, sizeof mate);
    memset(first, -1, sizeof first);

    int u = 0, ret = 0;
    for(int z = 0; z < n; ++z) {
        if(mate[z] != -1) continue;

        memset(label, -1, sizeof label);
        memset(type, -1, sizeof type);
        memset(g_souter, 0, sizeof g_souter);

        label[z] = -1; type[z] = 0;

```

```

        queue<int> outer;
        outer.push(z);

        bool done = false;
        while(!outer.empty()) {
            int x = outer.front(); outer.pop();

            if(g_souter[x]) continue;
            g_souter[x] = true;

            for(int i = last_edge[x]; i != -1; i = prev_edge[i]) {
                if(mate[w[i]] == -1 && w[i] != z) {
                    mate[w[i]] = x;
                    g_augment(x, w[i]);
                    ++ret;

                    done = true;
                    break;
                }

                if(type[w[i]] == -1) {
                    int v = mate[w[i]];
                    if(type[v] == -1) {
                        type[v] = 0;
                        label[v] = x;
                        outer.push(v);

                        first[v] = w[i];
                    }
                    continue;
                }
            }

            int r = first[x], s = first[w[i]];
            if(r == s) continue;

            memset(g_flag, 0, sizeof g_flag);
            g_flag[r] = g_flag[s] = true;

            while(true) {
                if(s != -1) swap(r, s);
                r = first[label[mate[r]]];
                if(g_flag[r]) break; g_flag[r] = true;
            }

            g_label(first[x], r, i, outer);

```

```

        g_label(first[w[i]], r, i, outer);

    for(int c = 0; c < n; ++c)
        if(type[c] != -1 && first[c] != -1 && type[first[c]] != -1)
            first[c] = r;
}

```

```

        if(done) break;
    }
}
return ret;
}

```

3. MATH

3.1. Fractions. Hash: 85739ae11b5b0351c0a9b5b6f813eaf8

```

struct frac {
    long long num, den;
    frac(long long num = 0, long long den = 1) { set_val(num, den); }

    void set_val(long long _num, long long _den) {
        num = _num/__gcd(_num, _den);
        den = _den/__gcd(_num, _den);
        if(den < 0) { num *= -1; den *= -1; }
    }

    void operator*=(frac f) { set_val(num * f.num, den * f.den); }
    void operator+=(frac f) { set_val(num * f.den + f.num * den, den * f.den); }
    void operator-=(frac f) { set_val(num * f.den - f.num * den, den * f.den); }
    void operator/=(frac f) { set_val(num * f.den, den * f.num); }
};

```

```

bool operator==(frac a, frac b) { return a.num * b.den == b.num * a.den; }
bool operator!=(frac a, frac b) { return !(a == b); }
bool operator<(frac a, frac b) { return a.num * b.den < b.num * a.den; }
bool operator<=(frac a, frac b) { return (a == b) || (a < b); }
bool operator>(frac a, frac b) { return !(a <= b); }
bool operator>=(frac a, frac b) { return !(a < b); }
frac operator/(frac a, frac b) { frac ret = a; ret /= b; return ret; }
frac operator*(frac a, frac b) { frac ret = a; ret *= b; return ret; }
frac operator+(frac a, frac b) { frac ret = a; ret += b; return ret; }
frac operator-(frac a, frac b) { frac ret = a; ret -= b; return ret; }
frac operator-(frac f) { return 0 - f; }

std::ostream& operator<<(std::ostream& o, const frac f) {
    o << f.num << "/" << f.den;
    return o;
}

```

3.2. Chinese remainder theorem. Hash: 06b5ebd5c44c204a4b11bbb76d09023d

```

struct t {
    long long a, b; int g;
    t(long long a, long long b, int g) : a(a), b(b), g(g) { }
    t swap() { return t(b, a, g); }
};

t egcd(int p, int q) {
    if(q == 0) return t(1, 0, p);

    t t2 = egcd(q, p % q);

```

```

    t2.a -= t2.b * (p/q);
    return t2.swap();
}

int crt(int a, int p, int b, int q) {
    t t2 = egcd(p, q); t2.a %= p*q; t2.b %= p*q;
    assert(t2.g == 1);
    int ret = ((b * t2.a)%(p*q) * p + (a * t2.b)%(p*q) * q) % (p*q);
    return ret >= 0 ? ret : ret + p*q;
}

```

3.3. Longest increasing subsequence. Hash: 0c94974a1a54f572893029cececcbe23

```
vector<int> lis(vector<int>& seq) {
    int smallest_end[seq.size()+1], prev[seq.size()];
    smallest_end[1] = seq[0];

    int sz = 1;
    for(int i = 1; i < seq.size(); ++i) {
        int lo = 0, hi = sz;
        while(lo < hi) {
            int mid = (lo + hi + 1)/2;
            if(seq[smallest_end[mid]] <= seq[i])
                lo = mid;
            else
                hi = mid - 1;
        }
    }
```

```
        prev[i] = smallest_end[lo];
        if(lo == sz)
            smallest_end[++sz] = i;
        else if(seq[i] < seq[smallest_end[lo+1]])
            smallest_end[lo+1] = i;
    }

    vector<int> ret;
    for(int cur = smallest_end[sz]; sz > 0; cur = prev[cur], --sz)
        ret.push_back(seq[cur]);
    reverse(ret.begin(), ret.end());

    return ret;
}
```

3.4. Simplex (Warsaw University). Hash: c687094970cf1953fd6f87a01adc6a95

```
const double EPS = 1e-9;
typedef long double T;
typedef vector<T> VT;
vector<VT> A;
VT b,c,res;
VI kt,N;
int m;
inline void pivot(int k,int l,int e){
    int x=kt[l]; T p=A[l][e];
    REP(i,k) A[l][i]/=p; b[l]/=p; N[e]=0;
    REP(i,m) if (i!=l) b[i]-=A[i][e]*b[l],A[i][x]=A[i][e]*-A[l][x];
    REP(j,k) if (N[j]){
        c[j]-=c[e]*A[l][j];
        REP(i,m) if (i!=l) A[i][j]-=A[i][e]*A[l][j];
    }
    kt[l]=e; N[x]=1; c[x]=c[e]*-A[l][x];
}

VT doit(int k){
    VT res; T best;
    while (1){
        int e=-1,l=-1; REP(i,k) if (N[i] && c[i]>EPS) {e=i; break;}
        if (e==-1) break;
        REP(i,m) if (A[i][e]>EPS && (l==-1 || best>b[i]/A[i][e]))
            best=b[i] l=i ]/A[i][e];
    }
```

```
        if (l==-1) /*ilimitado*/ return VT();
        pivot(k,l,e);
    }
    res.resize(k,0); REP(i,m) res[kt[i]]=b[i];
    return res;
}

VT simplex(vector<VT> &AA,VT &bb,VT &cc){
    int n=AA[0].size(),k;
    m=AA.size(); k=n+m+1; kt.resize(m); b=bb; c=cc; c.resize(n+m);
    A=AA; REP(i,m){ A[i].resize(k); A[i][n+i]=1; A[i][k-1]=-1; kt[i]=n+i;}
    N=VI(k,l); REP(i,m) N[kt[i]]=0;
    int pos=min_element(ALL(b))-b.begin();
    if (b[pos]<-EPS){
        c=VT(k,0); c[k-1]=-1; pivot(k,pos,k-1); res=doit(k);
        if (res[k-1]>EPS) /*impossivel*/ return VT();
        REP(i,m) if (kt[i]==k-1)
            REP(j,k-1) if (N[j] && (A[i][j]<-EPS || EPS<A[i][j])){
                pivot(k,i,j); break;
            }
        c=cc; c.resize(k,0); REP(i,m) REP(j,k) if (N[j]) c[j]-=c[kt[i]]*A[i][j];
    }
    res=doit(k-1); if (!res.empty()) res.resize(n);
    return res;
}
```

3.5. Romberg's method. Hash: a56c42a3dac08d2c5fc932f92468dd03

```
long double romberg(int a, int b, double(*func)(double)) {
    long double approx[2][50];
    long double *cur=approx[1], *prev=approx[0];

    prev[0] = 1/2.0 * (b-a) * (func(a) + func(b));
    for(int it = 1; it < 25; ++it, swap(cur, prev)) {
        if(it > 1 && cmp(prev[it-1], prev[it-2]) == 0)
            return prev[it-1];

        cur[0] = 1/2.0 * prev[0];
```

```
        long double div = (b-a)/pow(2, it);
        for(long double sample = a + div; sample < b; sample += 2 * div)
            cur[0] += div * func(a + sample);

        for(int j = 1; j <= it; ++j)
            cur[j] = cur[j-1] + 1/(pow(4, it) - 1)*(cur[j-1] + prev[j-1]);
    }

    return prev[24];
}
```

3.6. Floyd's cycle detection algorithm. Hash: 97a42d1ac6750f912c5a06e04636c1db

```
pair<int, int> floyd(int x0) {
    int t = f(x0), h = f(f(x0)), start = 0, length = 1;
    while(t != h)
        t = f(t), h = f(f(h));

    h = t; t = x0;
    while(t != h)
        t = f(t), h = f(h), ++start;
```

```
    h = f(t);
    while(t != h)
        h = f(h), ++length;

    return make_pair(start, length);
}
```

3.7. Pollard's rho algorithm. Hash: ad4ee1d4afc564b2c55f90d6269994c4

```
long long pollard_r, pollard_n;

inline long long f(long long val) { return (val*val + pollard_r) % pollard_n; }
inline long long myabs(long long a) { return a >= 0 ? a : -a; }

long long pollard(long long n) {
    srand(unsigned(time(0)));
    pollard_n = n;

    long long d = 1;
    do {
```

```
        d = 1;
        pollard_r = rand() % n;

        long long x = 2, y = 2;
        while(d == 1)
            x = f(x), y = f(f(y)), d = __gcd(myabs(x-y), n);
    } while(d == n);

    return d;
}
```

3.8. Miller-Rabin's algorithm. Hash: 5288cd2ac5d62a97ea1175eec20d0010

```
int fastpow(int base, int d, int n) {
```

```
    int ret = 1;
```



```

    for(long long pow = base; d > 0; d >= 1, pow = (pow * pow) % n)
        if(d & 1)
            ret = (ret * pow) % n;
    return ret;
}

```

```

bool miller_rabin(int n, int base) {
    if(n <= 1) return false;
    if(n % 2 == 0) return n == 2;

    int s = 0, d = n - 1;
    while(d % 2 == 0) d /= 2, ++s;

    int base_d = fastpow(base, d, n);
    if(base_d == 1) return true;
}

```

```
int base_2r = base_d;
```

```

for(int i = 0; i < s; ++i) {
    if(base_2r == 1) return false;
    if(base_2r == n - 1) return true;
    base_2r = (long long)base_2r * base_2r % n;
}

```

```
return false;
```

```
}
```

```

bool isprime(int n) {
    if(n == 2 || n == 7 || n == 61) return true;
    return miller_rabin(n, 2) && miller_rabin(n, 7) && miller_rabin(n, 61);
}

```

3.9. Karatsuba's algorithm. Hash: baa2224f03b35ae422eed1c261dcf6b8

```
typedef vector<int> poly;
```

```

poly mult(const poly& p, const poly& q) {
    int sz = p.size(), half = sz/2;
    assert(sz == q.size() && !(sz&(sz-1)));
}

```

```

if(sz <= 64) {
    poly ret(2*sz);
    for(int i = 0; i < sz; i++)
        for(int j = 0; j < sz; j++)
            ret[i+j] += p[i] * q[j];
    return ret;
}

```

```
poly p1(p.begin(), p.begin() + half), p2(p.begin() + half, p.end());
```

```

poly q1(q.begin(), q.begin() + half), q2(q.begin() + half, q.end());
poly plp2(half), qlq2(half);
for(int i = 0; i < half; i++)
    plp2[i] = p1[i] + p2[i], qlq2[i] = q1[i] + q2[i];

```

```

poly low = mult(p1, q1), high = mult(p2, q2), mid = mult(plp2, qlq2);
for(int i = 0; i < sz; i++)
    mid[i] -= high[i] + low[i];

```

```

low.resize(2*sz);
for(int i = 0; i < sz; i++)
    low[i+half] += mid[i], low[i+sz] += high[i];

```

```
return low;
```

```
}
```

3.10. Optimized sieve of Erathostenes. Hash: f61dff82d061bab316148816c3b7ac01

```
const unsigned MAX = 1000000020/60, MAX_S = sqrt(MAX/60);
```

```

unsigned w[16] = {1, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 49, 53, 59};
unsigned short composite[MAX];
vector<int> primes;

```

```
void sieve() {
```

```
unsigned mod[16][16], di[16][16], num;
```

```

for(int i = 0; i < 16; i++)
    for(int j = 0; j < 16; j++) {
        di[i][j] = (w[i]*w[j])/60;
        mod[i][j] = lower_bound(w, w + 16, (w[i]*w[j])%60) - w;
    }

```

```

primes.push_back(2); primes.push_back(3); primes.push_back(5);

memset(composite, 0, sizeof composite);
for(unsigned i = 0; i < MAX; i++)
    for(int j = (i==0); j < 16; j++) {
        if(composite[i] & (1<<j)) continue;
        primes.push_back(num = 60*i + w[j]);

        if(i > MAX_S) continue;

```

```

        for(unsigned k = i, done = false; !done; k++)
            for(int l = (k==0); l < 16 && !done; l++) {
                unsigned mult = k*num + i*w[l] + di[j][l];
                if(mult >= MAX) done = true;
                else composite[mult] |= 1<<mod[j][l];
            }
    }
}

```

3.11. Polynomials (PUC-Rio). Hash: d69d1ad494e487327d2338e69eccfa2f

```

typedef complex<double> cdouble;
int cmp(cdouble x, cdouble y = 0) {
    return cmp(abs(x), abs(y));
}
const int TAM = 200;
struct poly {
    cdouble poly[TAM]; int n;
    poly(int n = 0): n(n) { memset(p, 0, sizeof(p)); }
    cdouble& operator [] (int i) { return p[i]; }
    poly operator ~() {
        poly r(n-1);
        for (int i = 1; i <= n; i++)
            r[i-1] = p[i] * cdouble(i);
        return r;
    }
}
pair<poly, cdouble> ruffini(cdouble z) {
    if (n == 0) return make_pair(poly(), 0);
    poly r(n-1);
    for (int i = n; i > 0; i--) r[i-1] = r[i] * z + p[i];
    return make_pair(r, r[0] * z + p[0]);
}
cdouble operator () (cdouble z) { return ruffini(z).second; }
cdouble find_one_root(cdouble x) {
    poly p0 = *this, p1 = ~p0, p2 = ~p1;
    int m = 1000;

```

```

    while (m--) {
        cdouble y0 = p0(x);
        if (cmp(y0) == 0) break;
        cdouble G = p1(x) / y0;
        cdouble H = G * G - p2(x) - y0;
        cdouble R = sqrt(cdouble(n-1) * (H * cdouble(n) - G * G));
        cdouble D1 = G + R, D2 = G - R;
        cdouble a = cdouble(n) / (cmp(D1, D2) > 0 ? D1 : D2);
        x -= a;
        if (cmp(a) == 0) break;
    }
    return x;
}
vector<cdouble> roots() {
    poly q = *this;
    vector<cdouble> r;
    while (q.n > 1) {
        cdouble z(rand() / double(RAND_MAX), rand() / double(RAND_MAX));
        z = q.find_one_root(z); z = find_one_root(z);
        q = q.ruffini(z).first;
        r.push_back(z);
    }
    return r;
}
};

```

4. GEOMETRY

4.1. Point class. Hash: 4a0fc00fd27520d94e04b2fc6c05ed73

```
typedef double TYPE;
const TYPE EPS = 1e-9, INF = 1e9;

inline int sgn(TYPE a) { return a > EPS ? 1 : (a < -EPS ? -1 : 0); }
inline int cmp(TYPE a, TYPE b) { return sgn(a - b); }

struct pt {
    TYPE x, y;
    pt(TYPE x = 0, TYPE y = 0) : x(x), y(y) { }

    bool operator==(pt p) { return cmp(x, p.x) == 0 && cmp(y, p.y) == 0; }
    bool operator<(pt p) const {
        return cmp(x, p.x) ? cmp(x, p.x) < 0 : cmp(y, p.y) < 0;
    }
    bool operator<=(pt p) { return *this < p || *this == p; }
    TYPE operator||(pt p) { return x*p.x + y*p.y; }
    TYPE operator%(pt p) { return x*p.y - y*p.x; }
    pt operator~() { return pt(x, -y); }
    pt operator+(pt p) { return pt(x + p.x, y + p.y); }
    pt operator-(pt p) { return pt(x - p.x, y - p.y); }
    pt operator*(pt p) { return pt(x*p.x - y*p.y, x*p.y + y*p.x); }
    pt operator/(TYPE t) { return pt(x/t, y/t); }
```

```
    pt operator/(pt p) { return (*this * ~p)/(p||p); }
};
const pt I = pt(0,1);

struct circle {
    pt c; TYPE r;
    circle(pt c, TYPE r) : c(c), r(r) { }
};

TYPE norm(pt a) { return a||a; }
TYPE abs(pt a) { return sqrt(a||a); }
TYPE dist(pt a, pt b) { return abs(a - b); }
TYPE area(pt a, pt b, pt c) { return (a-c)%(b-c); }
int ccw(pt a, pt b, pt c) { return sgn(area(a, b, c)); }
pt unit(pt a) { return a/abs(a); }
double arg(pt a) { return atan2(a.y, a.x); }
pt f_polar(TYPE mod, double ang) { return pt(mod * cos(ang), mod * sin(ang)); }
inline int g_mod(int i, int n) { if(i == n) return 0; return i; }

ostream& operator<<(ostream& o, pt p) {
    return o << "(" << p.x << "," << p.y << ")";
}
```

4.2. Intersection primitives. Hash: ab780978106a5c062b8f7a129ebc9196

```
bool in_rect(pt a, pt b, pt c) {
    return sgn(c.x - min(a.x, b.x)) >= 0 && sgn(max(a.x, b.x) - c.x) >= 0 &&
        sgn(c.y - min(a.y, b.y)) >= 0 && sgn(max(a.y, b.y) - c.y) >= 0;
}
bool ps_isects(pt a, pt b, pt c) { return ccw(a,b,c) == 0 && in_rect(a,b,c); }

bool ss_isects(pt a, pt b, pt c, pt d) {
    if (ccw(a,b,c)*ccw(a,b,d) == -1 && ccw(c,d,a)*ccw(c,d,b) == -1) return true;
    return ps_isects(a, b, c) || ps_isects(a, b, d) ||
        ps_isects(c, d, a) || ps_isects(c, d, b);
}
```

```
pt parametric_isect(pt p, pt v, pt q, pt w) {
    double t = ((q-p)%w)/(v%w);
    return p + v*t;
}

pt ss_isect(pt p, pt q, pt r, pt s) {
    pt isect = parametric_isect(p, q-p, r, s-r);
    if(ps_isects(p, q, isect) && ps_isects(r, s, isect)) return isect;
    return pt(1/0.0, 1/0.0);
}
```

4.3. Polygon primitives. Hash: 621a339a657d07de8f651d55e13d988b

```
double p_signedarea(vector<pt>& pol) {
    double ret = 0;
```

```
    for(int i = 0; i < pol.size(); ++i)
        ret += pol[i] % pol[g_mod(i+1, pol.size())];
```

```

    return ret/2;
}

int point_polygon(pt p, vector<pt>& pol) {
    int n = pol.size(), count = 0;

    for(int i = 0; i < n; ++i) {

```

```

        int il = g_mod(i+1, n);
        if (ps_isects(pol[i], pol[il], p)) return -1;
        else if((sgn(pol[i].y - p.y) == 1) != (sgn(pol[il].y - p.y) == 1)) &&
            ccw(pol[i], p, pol[il]) == sgn(pol[i].y - pol[il].y)) ++count;
    }
    return count % 2;
}

```

4.4. Miscellaneous primitives. Hash: be051245293a9db9c991d414c598e854

```

bool point_circle(pt p, circle c) {
    return cmp(abs(p - c.c), c.r) <= 0;
}

double ps_distance(pt p, pt a, pt b) {
    p = p - a; b = b - a;
    double coef = min(max((b||p)/(b||b), TYPE(0)), TYPE(1));
    return abs(p - b*coef);
}

```

```

pt circumcenter(pt a, pt b, pt c) {
    return parametric_isect((b+a)/2, (b-a)*I, (c+a)/2, (c-a)*I);
}

bool compy(pt a, pt b) {
    return cmp(a.y, b.y) ? cmp(a.y, b.y) < 0 : cmp(a.x, b.x) < 0;
}

bool compx(pt a, pt b) { return a < b; }

```

4.5. Smallest enclosing circle. Hash: 00dd4dbd6779989a64c1e935443a1d80

```

circle enclosing_circle(vector<pt>& pts) {
    srand(unsigned(time(0)));
    random_shuffle(pts.begin(), pts.end());

    circle c(pt(), -1);
    for(int i = 0; i < pts.size(); ++i) {
        if(point_circle(pts[i], c)) continue;
        c = circle(pts[i], 0);
        for(int j = 0; j < i; ++j) {
            if(point_circle(pts[j], c)) continue;

```

```

            c = circle((pts[i] + pts[j])/2, abs(pts[i] - pts[j])/2);
            for(int k = 0; k < j; ++k) {
                if(point_circle(pts[k], c)) continue;
                pt center = circumcenter(pts[i], pts[j], pts[k]);
                c = circle(center, abs(center - pts[i])/2);
            }
        }
    }
    return c;
}

```

4.6. Convex hull. Hash: 2b14ae1a97e5ff686efb4d7e0e7ca78a

```

pt pivot;

bool hull_comp(pt a, pt b) {
    int turn = ccw(a, b, pivot);
    return turn == 1 || (turn == 0 && cmp(norm(a-pivot), norm(b-pivot)) < 0);
}

```

```

vector<pt> hull(vector<pt> pts) {
    if(pts.size() <= 1) return pts;
    vector<pt> ret;

    int mini = 0;
    for(int i = 1; i < pts.size(); ++i)
        if(pts[i] < pts[mini])

```

```

        mini = i;

    pivot = pts[mini];
    swap(pts[0], pts[mini]);
    sort(pts.begin() + 1, pts.end(), hull_comp);

    ret.push_back(pts[0]);
    ret.push_back(pts[1]);
    int sz = 2;

```

4.7. Closest pair of points. Hash: d704271ff258aac5dad13bb04cf0cfb6

```

pair<pt, pt> closest_points_rec(vector<pt>& px, vector<pt>& py) {
    pair<pt, pt> ret;
    double d;

    if(px.size() <= 3) {
        double best = 1e10;
        for(int i = 0; i < px.size(); ++i)
            for(int j = i + 1; j < px.size(); ++j)
                if(dist(px[i], px[j]) < best) {
                    ret = make_pair(px[i], px[j]);
                    best = dist(px[i], px[j]);
                }

        return ret;
    }

    pt split = px[(px.size() - 1)/2];
    vector<pt> qx, qy, rx, ry;
    for(int i = 0; i < px.size(); ++i)
        if(px[i] <= split) qx.push_back(px[i]);
        else rx.push_back(px[i]);

    for(int i = 0; i < py.size(); ++i)
        if(py[i] <= split) qy.push_back(py[i]);
        else ry.push_back(py[i]);

    ret = closest_points_rec(qx, qy);
    pair<pt, pt> rans = closest_points_rec(rx, ry);
    double delta = dist(ret.first, ret.second);

    if((d = dist(rans.first, rans.second)) < delta) {

```

```

        for(int i = 2; i < pts.size(); ++i) {
            while(sz >= 2 && ccw(ret[sz-2], ret[sz-1], pts[i]) <= 0)
                ret.pop_back(), --sz;
            ret.push_back(pts[i]), ++sz;
        }

        return ret;
    }
}

```

```

        delta = d;
        ret = rans;
    }

    vector<pt> s;
    for(int i = 0; i < py.size(); ++i)
        if(cmp(abs(py[i].x - split.x), delta) <= 0)
            s.push_back(py[i]);

    for(int i = 0; i < s.size(); ++i)
        for(int j = i + 1; j <= 7 && i + j < s.size(); ++j)
            if((d = dist(s[i], s[i+j])) < delta) {
                delta = d;
                ret = make_pair(s[i], s[i+j]);
            }

    return ret;
}

pair<pt, pt> closest_points(vector<pt> pts) {
    if(pts.size() == 1) return make_pair(pt(-INF, -INF), pt(INF, INF));

    sort(pts.begin(), pts.end());
    for(int i = 0; i + 1 < pts.size(); ++i)
        if(pts[i] == pts[i+1])
            return make_pair(pts[i], pts[i+1]);

    vector<pt> py = pts;
    sort(py.begin(), py.end(), compy);
    return closest_points_rec(pts, py);
}

```

4.8. Kd-tree. Hash: de78e67c89c057ba920d2060641a7f48

```

int tree[4*MAXSZ], val[4*MAXSZ];
TYPE split[4*MAXSZ];
vector<pt> pts;

void kd_recurse(int root, int left, int right, bool x) {
    if(left == right) {
        tree[root] = left;
        val[root] = 1;
        return;
    }

    int mid = (right+left)/2;
    nth_element(pts.begin() + left, pts.begin() + mid,
        pts.begin() + right + 1, x ? compx : compy);
    split[root] = x ? pts[mid].x : pts[mid].y;

    kd_recurse(2*root+1, left, mid, !x);
    kd_recurse(2*root+2, mid+1, right, !x);

    val[root] = val[2*root+1] + val[2*root+2];
}

void kd_build() {
    memset(tree, -1, sizeof tree);
    kd_recurse(0, 0, pts.size() - 1, true);
}

int kd_query(int root, TYPE a, TYPE b, TYPE c, TYPE d, TYPE ca = -INF,
    TYPE cb = INF, TYPE cc = -INF, TYPE cd = INF, bool x) {
    if(a <= ca && cb <= b && c <= cc && cd <= d) {
        return val[root];
    }

    if(tree[root] != -1)
        return a <= pts[tree[root]].x && pts[tree[root]].x <= b &&
            c <= pts[tree[root]].y && pts[tree[root]].y <= d ? val[root] : 0;
}

```

4.9. Range tree. Hash: 47db21e0b6328b90025fa4e9c03e3431

```

vector<pt> pts, tree[MAXSZ];
vector<TYPE> xs;
vector<int> lnk[MAXSZ][2];

```

```

int ret = 0;
if(x) {
    if(a <= split[root])
        ret += kd_query(2*root+1, a, b, c, d, ca, split[root], cc, cd, !x);
    if(split[root] <= b)
        ret += kd_query(2*root+2, a, b, c, d, split[root], cb, cc, cd, !x);
}
else {
    if(c <= split[root])
        ret += kd_query(2*root+1, a, b, c, d, ca, cb, cc, split[root], !x);
    if(split[root] <= d)
        ret += kd_query(2*root+2, a, b, c, d, ca, cb, split[root], cd, !x);
}
return ret;
}

pt kd_neighbor(int root, pt a, bool x) {
    if(tree[root] != -1)
        return a == pts[tree[root]] ? pt(2e9, 2e9) : pts[tree[root]];

    TYPE num = x ? a.x : a.y;
    int term = num <= split[root] ? 1 : 2;
    pt ret;

    TYPE d = norm(a - (ret = kd_neighbor(2*root + term, a, !x)));
    if((split[root] - num)*(split[root] - num) < d) {
        pt ret2 = kd_neighbor(2*root + 3 - term, a, !x);
        if(norm(a - ret2) < d)
            ret = ret2;
    }

    return ret;
}

```

```

int rt_recurse(int root, int left, int right) {
    if(left == right) {
        vector<pt>::iterator it;
        it = lower_bound(pts.begin(), pts.end(), pt(xs[left], -INF));
    }
}

```

```

    for(; it != pts.end() && it->x == xs[left]; ++it)
        tree[root].push_back(*it);

    sort(tree[root].begin(), tree[root].end(), compy);
    return tree[root].size();
}

int mid = (left + right)/2, cl = 2*root + 1, cr = cl + 1;
int sz1 = rt_recurse(cl, left, mid);
int sz2 = rt_recurse(cr, mid + 1, right);

int l = 0, r = 0, llink = 0, rlink = 0; pt last;
while(l < sz1 || r < sz2) {
    if(r == sz2 || (l < sz1 && compy(tree[cl][l], tree[cr][r])))
        tree[root].push_back(last = tree[cl][l++]);
    else tree[root].push_back(last = tree[cr][r++]);

    while(llink < tree[cl].size() && compy(tree[cl][llink], last))
        ++llink;
    while(rlink < tree[cr].size() && compy(tree[cr][rlink], last))
        ++rlink;

    lnk[root][0].push_back(llink);
    lnk[root][1].push_back(rlink);
}

lnk[root][0].push_back(tree[cl].size());
lnk[root][1].push_back(tree[cr].size());

return tree[root].size();

```

```

}

void rt_build() {
    sort(pts.begin(), pts.end());
    for(int i = 0; i < pts.size(); ++i) xs.push_back(pts[i].x);
    rt_recurse(0, 0, xs.size() - 1);
}

int rt_query(int root, int l, int r, TYPE a, TYPE b, TYPE c, TYPE d,
             int posl = -1, int posr = -1) {
    if(root == 0 && posl == -1) {
        posl = lower_bound(tree[0].begin(), tree[0].end(), pt(a, c), compy)
            - tree[0].begin();
        posr = upper_bound(tree[0].begin(), tree[0].end(), pt(b, d), compy)
            - tree[0].begin();
    }

    if(a <= xs[l] && xs[r] <= b)
        return posr - posl;
    if(posl >= tree[root].size()) return 0;

    int mid = (l + r)/2, ret = 0;
    if(a <= xs[mid])
        ret += rt_query(2*root+1, l, mid, a, b, c, d,
                        lnk[root][0][posl], lnk[root][0][posr]);
    if(xs[mid+1] <= b)
        ret += rt_query(2*root+2, mid+1, r, a, b, c, d,
                        lnk[root][1][posl], lnk[root][1][posr]);
    return ret;
}

```

5. DATA STRUCTURES

5.1. Treap. Hash: 2199b72803301716616a462d9d5e9a66

```

typedef int TYPE;

class treap {
public:
    treap *left, *right;
    int priority, sons;
    TYPE value;

    treap(TYPE value) : left(NULL), right(NULL), value(value), sons(0) {
        priority = rand();
    }

```

```

    }

    ~treap() {
        if(left) delete left;
        if(right) delete right;
    }
};

treap* find(treap* t, TYPE val) {
    if(!t) return NULL;

```

```

    if(val == t->value) return t;

    if(val < t->value) return find(t->left, val);
    if(val > t->value) return find(t->right, val);
}

void rotate_to_right(treap* &t) {
    treap* n = t->left;
    t->left = n->right;
    n->right = t;
    t = n;
}

void rotate_to_left(treap* &t) {
    treap* n = t->right;
    t->right = n->left;
    n->left = t;
    t = n;
}

void fix_augment(treap* t) {
    if(!t) return;
    t->sons = (t->left ? t->left->sons + 1 : 0) +
        (t->right ? t->right->sons + 1 : 0);
}

void insert(treap* &t, TYPE val) {
    if(!t)
        t = new treap(val);
    else

```

```

        insert(val <= t->value ? t->left : t->right, val);

    if(t->left && t->left->priority > t->priority)
        rotate_to_right(t);
    else if(t->right && t->right->priority > t->priority)
        rotate_to_left(t);

    fix_augment(t->left); fix_augment(t->right); fix_augment(t);
}

inline int p(treap* t) {
    return t ? t->priority : -1;
}

void erase(treap* &t, TYPE val) {
    if(!t) return;

    if(t->value != val)
        erase(val < t->value ? t->left : t->right, val);
    else {
        if(!t->left && !t->right)
            delete t, t = NULL;
        else {
            p(t->left) < p(t->right) ? rotate_to_left(t) : rotate_to_right(t);
            erase(t, val);
        }
    }

    fix_augment(t->left); fix_augment(t->right); fix_augment(t);
}

```

5.2. Heap. Hash: e334218955a73d1286ad0fc19e84b642

```

struct heap {
    int heap[MAXV][2], v2n[MAXV];
    int size;

    void init(int sz) __attribute__((always_inline)) {
        memset(v2n, -1, sizeof(int) * sz);
        size = 0;
    }

    void swap(int& a, int& b) __attribute__((always_inline)) {
        int temp = a;
        a = b;

```

```

        b = temp;
    }

    void s(int a, int b) __attribute__((always_inline)) {
        swap(v2n[heap[a][1]], v2n[heap[b][1]]);
        swap(heap[a][0], heap[b][0]);
        swap(heap[a][1], heap[b][1]);
    }

    int extract_min() {
        int ret = heap[0][1];
        s(0, --size);

```



```

int cur = 0, next = 2;
while(next < size) {
    if(heap[next][0] > heap[next - 1][0])
        next--;
    if(heap[next][0] >= heap[cur][0])
        break;

    s(next, cur);
    cur = next;
    next = 2*cur + 2;
}
if(next == size && heap[next - 1][0] < heap[cur][0])
    s(next - 1, cur);

return ret;
}

void decrease_key(int vertex, int new_value) __attribute__((always_inline))

```

```

{
    if(v2n[vertex] == -1) {
        v2n[vertex] = size;
        heap[size++][1] = vertex;
    }

    heap[v2n[vertex]][0] = new_value;

    int cur = v2n[vertex];
    while(cur >= 1) {
        int parent = (cur - 1)/2;
        if(new_value >= heap[parent][0])
            break;

        s(cur, parent);
        cur = parent;
    }
}
};

```

5.3. Big numbers (PUC-Rio). Hash: a7d74e7158634f9201c19235badd3364

```

const int DIG = 4;
const int BASE = 10000; // BASE**3 < 2**51
const int TAM = 2048;

struct bigint {
    int v[TAM], n;
    bigint(int x = 0): n(1) {
        memset(v, 0, sizeof(v));
        v[n++] = x; fix();
    }
    bigint(char *s): n(1) {
        memset(v, 0, sizeof(v));
        int sign = 1;
        while (*s && !isdigit(*s)) if (*s++ == '-') sign *= -1;
        char *t = strdup(s), *p = t + strlen(t);
        while (p > t) {
            *p = 0; p = max(t, p - DIG);
            sscanf(p, "%d", &v[n]);
            v[n++] *= sign;
        }
        free(t); fix();
    }
    bigint& fix(int m = 0) {

```

```

        n = max(m, n);
        int sign = 0;
        for (int i = 1, e = 0; i <= n || e && (n = i); i++) {
            v[i] += e; e = v[i] / BASE; v[i] %= BASE;
            if (v[i]) sign = (v[i] > 0) ? 1 : -1;
        }

        for (int i = n - 1; i > 0; i--)
            if (v[i] * sign < 0) { v[i] += sign * BASE; v[i+1] -= sign; }
        while (n && !v[n]) n--;
        return *this;
    }

    int cmp(const bigint& x = 0) const {
        int i = max(n, x.n), t = 0;
        while (1) if ((t = ::cmp(v[i], x.v[i])) || i-- == 0) return t;
    }
    bool operator <(const bigint& x) const { return cmp(x) < 0; }
    bool operator ==(const bigint& x) const { return cmp(x) == 0; }
    bool operator !=(const bigint& x) const { return cmp(x) != 0; }

    operator string() const {
        ostringstream s; s << v[n];

```

```

    for (int i = n - 1; i > 0; i--) {
        s.width(DIG); s.fill('0'); s << abs(v[i]);
    }
    return s.str();
}

friend ostream& operator <<(ostream& o, const bigint& x) {
    return o << (string) x;
}

bigint& operator +=(const bigint& x) {
    for (int i = 1; i <= x.n; i++) v[i] += x.v[i];
    return fix(x.n);
}

bigint operator +(const bigint& x) { return bigint(*this) += x; }
bigint& operator -(const bigint& x) {
    for (int i = 1; i <= x.n; i++) v[i] -= x.v[i];
    return fix(x.n);
}

bigint operator -(const bigint& x) { return bigint(*this) -= x; }
bigint operator -() { bigint r = 0; return r -= *this; }

void ams(const bigint& x, int m, int b) { // *this += (x * m) << b;
    for (int i = 1, e = 0; (i <= x.n || e) && (n = i + b); i++) {
        v[i+b] += x.v[i] * m + e; e = v[i+b] / BASE; v[i+b] %= BASE;
    }
}

bigint operator *(const bigint& x) const {
    bigint r;
    for (int i = 1; i <= n; i++) r.ams(x, v[i], i-1);
    return r;
}

bigint& operator *=(const bigint& x) { return *this = *this * x; }
// cmp(x / y) == cmp(x) * cmp(y); cmp(x % y) == cmp(x);
bigint div(const bigint& x) {
    if (x == 0) return 0;

```

```

    bigint q; q.n = max(n - x.n + 1, 0);
    int d = x.v[x.n] * BASE + x.v[x.n-1];
    for (int i = q.n; i > 0; i--) {
        int j = x.n + i - 1;
        q.v[i] = int((v[j] * double(BASE) + v[j-1]) / d);
        ams(x, -q.v[i], i-1);
        if (i == 1 || j == 1) break;
        v[j-1] += BASE * v[j]; v[j] = 0;
    }
    fix(x.n); return q.fix();
}

bigint& operator /=(const bigint& x) { return *this = div(x); }
bigint& operator %=(const bigint& x) { div(x); return *this; }
bigint operator /(const bigint& x) { return bigint(*this).div(x); }
bigint operator %(const bigint& x) { return bigint(*this) %= x; }
bigint pow(int x) {
    if (x < 0) return (*this == 1 || *this == -1) ? pow(-x) : 0;
    bigint r = 1;
    for (int i = 0; i < x; i++) r *= *this;
    return r;
}

bigint root(int x) {
    if (cmp() == 0 || cmp() < 0 && x % 2 == 0) return 0;
    if (*this == 1 || x == 1) return *this;
    if (cmp() < 0) return -(*this).root(x);
    bigint a = 1, d = *this;

    while (d != 1) {
        bigint b = a + (d /= 2);
        if (cmp(b.pow(x)) >= 0) { d += 1; a = b; }
    }
    return a;
}
};

```

6. STRING ALGORITHMS

6.1. Kärkkäinen-Sanders' suffix array algorithm. Hash: ad9edfdbf9c673ff57d1e2624bd0fc5b

```

bool k_cmp(int a1, int b1, int a2, int b2, int a3 = 0, int b3 = 0) {
    return a1 != b1 ? a1 < b1 : (a2 != b2 ? a2 < b2 : a3 < b3);
}

int bucket[MAXSZ+1], tmp[MAXSZ];
template<class T> void k_radix(T keys, int *in, int *out,

```

```

    int off, int n, int k) {
    memset(bucket, 0, sizeof(int) * (k+1));

    for(int j = 0; j < n; j++)
        bucket[keys[in[j]+off]]++;
    for(int j = 0, sum = 0; j <= k; j++)

```

```

        sum += bucket[j], bucket[j] = sum - bucket[j];
    for(int j = 0; j < n; j++)
        out[bucket[keys[in[j]+off]]++] = in[j];
}

int mod0[MAXSZ/3+1];
vector<int> k_rec(const vector<int>& v, int k) {
    int n = v.size()-3, sz = (n+2)/3, sz2 = sz + n/3;
    if(n < 2) return vector<int>(n);

    vector<int> sub(sz2+3);
    for(int i = 1, j = 0; j < sz2; i += i%3, j++)
        sub[j] = i;

    k_radix(v.begin(), &sub[0], tmp, 2, sz2, k);
    k_radix(v.begin(), tmp, &sub[0], 1, sz2, k);
    k_radix(v.begin(), &sub[0], tmp, 0, sz2, k);

    int last[3] = {-1, -1, -1}, unique = 0;
    for(int i = 0; i < sz2; i++) {
        bool diff = false;
        for(int j = 0; j < 3; last[j] = v[tmp[i]+j], j++)
            diff |= last[j] != v[tmp[i]+j];
        unique += diff;

        if(tmp[i]%3 == 1) sub[tmp[i]/3] = unique;
        else sub[tmp[i]/3 + sz] = unique;
    }

    vector<int> rec;
    if(unique < sz2) {
        rec = k_rec(sub, unique);
        rec.resize(sz2+sz);
        for(int i = 0; i < sz2; i++) sub[rec[i]] = i+1;
    } else {
        rec.resize(sz2+sz);
        for(int i = 0; i < sz2; i++) rec[sub[i]-1] = i;
    }

    for(int i = 0, j = 0; j < sz; i++)
        if(rec[i] < sz)
            tmp[j++] = 3*rec[i];
    k_radix(v.begin(), tmp, mod0, 0, sz, k);
    for(int i = 0; i < sz2; i++)

```

```

        rec[i] = rec[i] < sz ? 3*rec[i] + 1 : 3*(rec[i] - sz) + 2;

    int prec = sz2-1, pmod0 = sz-1, pret = sz2+sz-1;
    while(prec >= 0 && pmod0 >= 0)
        if(rec[prec]%3 == 1 && k_cmp(v[mod0[pmod0]], v[rec[prec]],
            sub[mod0[pmod0]/3], sub[rec[prec]/3+sz]) ||
            rec[prec]%3 == 2 && k_cmp(v[mod0[pmod0]], v[rec[prec]],
            v[mod0[pmod0]+1], v[rec[prec]+1],
            sub[mod0[pmod0]/3+sz], sub[rec[prec]/3+1]))
            rec[pret--] = rec[prec--];
        else
            rec[pret--] = mod0[pmod0--];
    if(pmod0 >= 0) memcpy(&rec[0], mod0, sizeof(int) * (pmod0+1));

    if(n%3==1) rec.erase(rec.begin());
    return rec;
}

vector<int> karkkainen(const string& s) {
    int n = s.size(), cnt = 1;
    vector<int> v(n + 3);

    for(int i = 0; i < n; i++) v[i] = i;
    k_radix(s.begin(), &v[0], tmp, 0, n, 256);
    for(int i = 0; i < n; cnt += (i+1 < n && s[tmp[i+1]] != s[tmp[i]]), i++)
        v[tmp[i]] = cnt;

    return k_rec(v, cnt);
}

vector<int> lcp(const string& s, const vector<int>& sa) {
    int n = sa.size();
    vector<int> prm(n), ans(n-1);
    for(int i = 0; i < n; i++) prm[sa[i]] = i;

    for(int h = 0, i = 0; i < n; i++)
        if(prm[i]) {
            int j = sa[prm[i]-1], ij = max(i, j);
            while(ij + h < n && s[i+h] == s[j+h]) h++;
            ans[prm[i]-1] = h;
            if(h) h--;
        }
    return ans;
}

```

6.2. Morris-Pratt's algorithm. Hash: 0234dfb6e26b39d35704838d84f1e86e

```
int pi[MAXSZ], res[MAXSZ], nres;

void morris_pratt(string text, string pattern) {
    nres = 0;
    pi[0] = -1;
    for(int i = 1; i < pattern.size(); ++i) {
        pi[i] = pi[i-1];
        while(pi[i] >= 0 && pattern[pi[i] + 1] != pattern[i])
            pi[i] = pi[pi[i]];
        if(pattern[pi[i] + 1] == pattern[i]) ++pi[i];
    }
}
```

```
int k = -1; //k + 1 eh o tamanho do match atual
for(int i = 0; i < text.size(); ++i) {
    while(k >= 0 && pattern[k + 1] != text[i])
        k = pi[k];
    if(pattern[k + 1] == text[i]) ++k;
    if(k + 1 == pattern.size()) {
        res[nres++] = i - k;
        k = pi[k];
    }
}
```

6.3. Aho-Corasick's algorithm (UFPE). Hash: 273f4391174d22898bfe3f2415f95915

```
struct No {
    int fail;
    vector< pair<int,int> > out; // num e tamanho do padrao
    //bool marc; // p/ decisao
    map<char, int> lista;
    int next; // aponta para o proximo sufixo que tenha out.size > 0
};

No arvore[1000003]; // quantida maxima de nos
//bool encontrado[1005]; // quantidade maxima de padroes, p/ decisao
int qtdNos, qtdPadroes;

// Funcao para inicializar
void inic() {
    arvore[0].fail = -1;
    arvore[0].lista.clear();
    arvore[0].out.clear();
    arvore[0].next = -1;
    qtdNos = 1;
    qtdPadroes = 0;
    //arvore[0].marc = false; // p/ decisao
    //memset(encontrado, false, sizeof(encontrado)); // p/ decisao
}

// Funcao para adicionar um padrao
void adicionar(char *padrao) {
    int no = 0, len = 0;
    for (int i = 0 ; padrao[i] ; i++, len++) {
```

```
        if (arvore[no].lista.find(padrao[i]) == arvore[no].lista.end()) {
            arvore[qtdNos].lista.clear(); arvore[qtdNos].out.clear();
            //arvore[qtdNos].marc = false; // p/ decisao
            arvore[no].lista[padrao[i]] = qtdNos;
            no = qtdNos++;
        } else no = arvore[no].lista[padrao[i]];
    }
    arvore[no].out.push_back(pair<int,int>(qtdPadroes++, len));
}

// Ativar Aho-corasick, ajustando funcoes de falha
void ativar() {
    int no, v, f, w;
    queue<int> fila;
    for (map<char,int>::iterator it = arvore[0].lista.begin();
        it != arvore[0].lista.end() ; it++) {
        arvore[no = it->second].fail = 0;
        arvore[no].next = arvore[0].out.size() ? 0 : -1;
        fila.push(no);
    }
    while (!fila.empty()) {
        no = fila.front(); fila.pop();
        for (map<char,int>::iterator it=arvore[no].lista.begin();
            it!=arvore[no].lista.end(); it++) {
            char c = it->first;
            v = it->second;
            fila.push(v);
        }
    }
}
```

```

        f = arvore[no].fail;
        while (arvore[f].lista.find(c) == arvore[f].lista.end()) {
            if (f == 0) { arvore[0].lista[c] = 0; break; }
            f = arvore[f].fail;
        }
        w = arvore[f].lista[c];
        arvore[v].fail = w;
        arvore[v].next = arvore[w].out.size() ? w : arvore[w].next;
    }
}

// Buscar padroes no aho-corasik
void buscar(char *input) {
    int v, no = 0;
    for (int i = 0 ; input[i] ; i++) {
        while (arvore[no].lista.find(input[i]) == arvore[no].lista.end()) {
            if (no == 0) { arvore[0].lista[input[i]] = 0; break; }

```

```

        no = arvore[no].fail;
    }
    v = no = arvore[no].lista[input[i]];
    // marcar os encontrados
    while (v != -1 /* && !arvore[v].marc */) { // p/ decisao
        //arvore[v].marc = true; // p/ decisao: nao continua a lista
        for (int k = 0 ; k < arvore[v].out.size() ; k++) {
            //encontrado[arvore[v].out[k].first] = true; // p/ decisao
            printf("Padrao_%d_na_posicao_%d\n", arvore[v].out[k].first,
                i-arvore[v].out[k].second+1);
        }
        v = arvore[v].next;
    }
}
// for (int i = 0 ; i < qtdPadroes ; i++)
//printf("%s\n", encontrado[i]?"y":"n"); // p/ decisao
}

```

7. USEFUL MATHEMATICAL FACTS

7.1. Prime counting function ($\pi(x)$). The prime counting function is asymptotic to $\frac{x}{\log x}$, by the prime number theorem.

x	10	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁸
$\pi(x)$	4	25	168	1.229	9.592	78.498	664.579	5.761.455

7.2. Partition function. The partition function $p(x)$ counts show many ways there are to write the integer x as a sum of integers.

x	36	37	38	39	40	41	42
p(x)	17.977	21.637	26.015	31.185	37.338	44.583	53.174
x	43	44	45	46	47	100	
p(x)	63.261	75.175	89.134	105.558	125.754	190.569.292	

7.3. Catalan numbers. Catalan numbers are defined by the recurrence:

$$C_{n+1} = \sum_{i=0}^n C_i C_{n-i}$$

A closed formula for Catalan numbers is:

$$C_n = \frac{1}{n+1} \binom{2n}{n} = \binom{2n}{n} - \binom{2n}{n+1}$$

7.4. Stirling numbers of the first kind. These are the number of permutations of I_n with exactly k disjoint cycles. They obey the recurrence:

$$\begin{bmatrix} n \\ k \end{bmatrix} = (n-1) \begin{bmatrix} n-1 \\ k \end{bmatrix} + \begin{bmatrix} n-1 \\ k-1 \end{bmatrix}$$

7.5. Stirling numbers of the second kind. These are the number of ways to partition I_n into exactly k sets. They obey the recurrence:

$$\begin{Bmatrix} n \\ k \end{Bmatrix} = k \begin{Bmatrix} n-1 \\ k \end{Bmatrix} + \begin{Bmatrix} n-1 \\ k-1 \end{Bmatrix}$$

A “closed” formula for it is:

$$\begin{Bmatrix} n \\ k \end{Bmatrix} = \frac{1}{k!} \sum_{j=0}^k (-1)^{k-j} \binom{k}{j} j^n$$

7.6. Bell numbers. These count the number of ways to partition I_n into subsets. They obey the recurrence:

$$\mathcal{B}_{n+1} = \sum_{k=0}^n \binom{n}{k} \mathcal{B}_k$$

x	5	6	7	8	9	10	11	12
\mathcal{B}_x	52	203	877	4.140	21.147	115.975	678.570	4.213.597

7.7. Turán’s theorem. No graph with n vertices that is K_{r+1} -free can have more edges than the Turán graph: A k -partite complete graph with sets of size as equal as possible.

7.8. Generating functions. A list of generating functions for useful sequences:

$(1, 1, 1, 1, 1, \dots)$	$\frac{1}{1-z}$
$(1, -1, 1, -1, 1, \dots)$	$\frac{1}{1+z}$
$(1, 0, 1, 0, 1, 0, \dots)$	$\frac{1}{1-z^2}$
$(1, 0, \dots, 0, 1, 0, 1, 0, \dots, 0, 1, 0, \dots)$	$\frac{1}{1-z^2}$
$(1, 2, 3, 4, 5, 6, \dots)$	$\frac{1}{(1-z)^2}$
$(1, \binom{m+1}{m}, \binom{m+2}{m}, \binom{m+3}{m}, \dots)$	$\frac{1}{(1-z)^{m+1}}$
$(1, c, \binom{c+1}{2}, \binom{c+2}{3}, \dots)$	$\frac{1}{(1-z)^c}$
$(1, c, c^2, c^3, \dots)$	$\frac{1}{1-cz}$
$(0, 1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots)$	$\ln \frac{1}{1-z}$

A neat manipulation trick is:

$$\frac{1}{1-z} G(z) = \sum_n \sum_{k \leq n} g_k z^n$$

7.9. Polyominoes. How many free (rotation, reflection), one-sided (rotation) and fixed n -ominoes are there?

n	3	4	5	6	7	8	9	10
free	2	5	12	35	108	369	1.285	4.655
one-sided	2	7	18	60	196	704	2.500	9.189
fixed	6	19	63	216	760	2.725	9.910	36.446

7.10. The twelvefold way (from Stanley). How many functions $f: N \rightarrow X$ are there?

N	X	Any f	Injective	Surjective
dist.	dist.	x^n	$(x)_n$	$x! \begin{Bmatrix} n \\ x \end{Bmatrix}$
indist.	dist.	$\binom{x+n-1}{n}$	$\binom{x}{n}$	$\binom{n-1}{n-x}$
dist.	indist.	$\begin{Bmatrix} n \\ 1 \end{Bmatrix} + \dots + \begin{Bmatrix} n \\ x \end{Bmatrix}$	$[n \leq x]$	$\begin{Bmatrix} n \\ k \end{Bmatrix}$
indist.	indist.	$p_1(n) + \dots + p_x(n)$	$[n \leq x]$	$p_x(n)$

Where $\begin{pmatrix} a \\ b \end{pmatrix} = \frac{1}{b!} (a)_b$ and $p_x(n)$ is the number of ways to partition the integer n using x summands.

7.11. Common integral substitutions. And finally, a list of common substitutions:

$\int F(\sqrt{ax+b})dx$	$u = \sqrt{ax+b}$	$\frac{2}{a} \int uF(u)du$
$\int F(\sqrt{a^2-x^2})dx$	$x = a \sin u$	$a \int F(a \cos u) \cos u du$
$\int F(\sqrt{x^2+a^2})dx$	$x = a \tan u$	$a \int F(a \sec u) \sec^2 u du$
$\int F(\sqrt{x^2-a^2})dx$	$x = a \sec u$	$a \int F(a \tan u) \sec u \tan u du$
$\int F(e^{ax})dx$	$u = e^{ax}$	$\frac{1}{a} \int \frac{F(u)}{u} du$
$\int F(\ln x)dx$	$u = \ln x$	$\int F(u)e^u du$

7.12. Table of non-trigonometric integrals. Some useful integrals are:

$\int \frac{dx}{x^2+a^2}$	$\frac{1}{a} \arctan \frac{x}{a}$
$\int \frac{dx}{x^2-a^2}$	$\frac{1}{2a} \ln \frac{x-a}{x+a}$
$\int \frac{dx}{a^2-x^2}$	$\frac{1}{2a} \ln \frac{a+x}{a-x}$
$\int \frac{dx}{\sqrt{a^2-x^2}}$	$\arcsin \frac{x}{a}$
$\int \frac{dx}{\sqrt{x^2-a^2}}$	$\ln(u + \sqrt{x^2-a^2})$
$\int \frac{dx}{x\sqrt{x^2-a^2}}$	$\frac{1}{a} \operatorname{arcsec} \left \frac{u}{a} \right $
$\int \frac{dx}{x\sqrt{x^2+a^2}}$	$-\frac{1}{a} \ln \left(\frac{a+\sqrt{x^2+a^2}}{x} \right)$
$\int \frac{dx}{x\sqrt{a^2-x^2}}$	$-\frac{1}{a} \ln \left(\frac{a+\sqrt{a^2-x^2}}{x} \right)$

7.13. Table of trigonometric integrals. A list of common and not-so-common trigonometric integrals:

$\int \tan x dx$	$-\ln \cos x $
$\int \cot x dx$	$\ln \sin x $
$\int \sec x dx$	$\ln \sec x + \tan x $
$\int \csc x dx$	$\ln \csc x - \cot x $
$\int \sec^2 x dx$	$\tan x$
$\int \csc^2 x dx$	$\cot x$
$\int \sin^n x dx$	$\frac{-\sin^{n-1} x \cos x}{n} + \frac{n-1}{n} \int \sin^{n-2} x dx$
$\int \cos^n x dx$	$\frac{\cos^{n-1} x \sin x}{n} + \frac{n-1}{n} \int \cos^{n-2} x dx$
$\int \arcsin x dx$	$x \arcsin x + \sqrt{1-x^2}$
$\int \arccos x dx$	$x \arccos x - \sqrt{1-x^2}$
$\int \arctan x dx$	$x \arctan x - \frac{1}{2} \ln 1-x^2 $

ACM ICPC TEAM REFERENCE - CONTENTS

Team Anuncie Aqui
Universidade Federal de Sergipe

CONTENTS

1. Configuration files and scripts	1	4.6. Convex hull	12
2. Graph algorithms	2	4.7. Closest pair of points	13
2.1. Tarjan's SCC algorithm	2	4.8. Kd-tree	14
2.2. Dinic's maximum flow algorithm	3	4.9. Range tree	14
2.3. Successive shortest paths mincost maxflow algorithm	3	5. Data structures	15
2.4. Gabow's general matching algorithm (WRONG)	4	5.1. Treap	15
3. Math	6	5.2. Heap	16
3.1. Fractions	6	5.3. Big numbers (PUC-Rio)	17
3.2. Chinese remainder theorem	6	6. String algorithms	18
3.3. Longest increasing subsequence	7	6.1. Kärkkäinen-Sanders' suffix array algorithm	18
3.4. Simplex (Warsaw University)	7	6.2. Morris-Pratt's algorithm	20
3.5. Romberg's method	8	6.3. Aho-Corasick's algorithm (UFPE)	20
3.6. Floyd's cycle detection algorithm	8	7. Useful mathematical facts	22
3.7. Pollard's rho algorithm	8	7.1. Prime counting function ($\pi(x)$)	22
3.8. Miller-Rabin's algorithm	8	7.2. Partition function	22
3.9. Karatsuba's algorithm	9	7.3. Catalan numbers	22
3.10. Optimized sieve of Erathostenes	9	7.4. Stirling numbers of the first kind	22
3.11. Polynomials (PUC-Rio)	10	7.5. Stirling numbers of the second kind	22
4. Geometry	10	7.6. Bell numbers	22
4.1. Point class	11	7.7. Turán's theorem	22
4.2. Intersection primitives	11	7.8. Generating functions	22
4.3. Polygon primitives	11	7.9. Polyominoes	23
4.4. Miscellaneous primitives	12	7.10. The twelvefold way (from Stanley)	23
4.5. Smallest enclosing circle	12	7.11. Common integral substitutions	23
		7.12. Table of non-trigonometric integrals	23
		7.13. Table of trigonometric integrals	23