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

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

```cpp
#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: 3d598e293de54a302a6492c57304d745

```cpp
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;

void 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]);
```

```cpp
   }

   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: 3a41582d750893ec5cd598e8c9c0e2b2

```cpp
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]);
```

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

    return false;
}

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[i^1] -= 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

```cpp
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];
```

```cpp
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. Kuhn-Munkres' weighted bipartite matching algorithm. Hash: a6cca19c70194378fb24a3d89b82eb53

```
int w[MAXV][MAXV], s[MAXV], rem[MAXV], remx[MAXV];
int mx[MAXV], my[MAXV], lx[MAXV], ly[MAXV];

void add(int x, int n) {
    s[x] = true;
    for(int y = 0; y < n; y++)
        if(rem[y] != -INF && rem[y] > lx[x] + ly[y] - w[x][y])
            rem[y] = lx[x] + ly[y] - w[x][y], remx[y] = x;
}
```

```
int kuhn_munkres(int n) {
    for(int i = 0; i < n; i++) mx[i] = my[i] = -1, lx[i] = ly[i] = 0;
    for(int i = 0; i < n; i++)
        for(int j = 0; j < n; j++)
            ly[j] = max(ly[j], w[i][j]);

    for(int i = 0; i < n; i++) {
        memset(s, 0, sizeof s); memset(rem, 0x3f, sizeof rem);
```

```
    int st;
    for(st = 0; st < n; st++) if(mx[st] == -1) { add(st, n); break; }
    while(mx[st] == -1) {
        int miny = -1;
        for(int y = 0; y < n; y++)
            if(rem[y] != -INF && (miny == -1 || rem[miny] >= rem[y]))
                miny = y;

        if(rem[miny]) {
            for(int x = 0; x < n; x++) if(s[x]) lx[x] -= rem[miny];
            for(int y = 0, d = rem[miny]; y < n; y++)
                if(rem[y] == -INF) ly[y] += d; else rem[y] -= d;
        }

        if(my[miny] == -1) {
            int cur = miny;
```

```
            while(remx[cur] != st) {
                int pmate = mx[remx[cur]];
                my[cur] = remx[cur], mx[my[cur]] = cur;
                my[pmate] = -1; cur = pmate;
            }
            my[cur] = remx[cur], mx[my[cur]] = cur;
        } else
            add(my[miny], n), rem[miny] = -INF;
    }
}

int ret = 0;
for(int i = 0; i < n; i++)
    ret += w[i][mx[i]];
return ret;
}
```

2.5. Gomory-Hu tree. Hash: 61170139df2a1bd22618717b1d57ed1a

```
bool cut[MAXV];
int mincut(int s, int t) {
    memset(flow, 0, sizeof flow);
    memset(cut, 0, sizeof cut);
    int ret = dinic(s, t);

    queue<int> q;
    q.push(s); cut[s] = true;
    while(!q.empty()) {
        int v = q.front(); q.pop();
        for(int i = last_edge[v]; i != -1; i = prev_edge[i]) {
            int w = adj[i];
            if(cap[i] - flow[i] && !cut[w])
                cut[w] = true, q.push(w);
        }
```

```
    }

    return ret;
}

int up[MAXV], val[MAXV];
void gomory_hu(int n) {
    memset(up, 0, sizeof up);
    for(int i = 1; i < n; i++) {
        val[i] = mincut(i, up[i]);
        for(int j = i+1; j < n; j++)
            if(cut[j] && up[j] == up[i])
                up[j] = i;
    }
}
```

2.6. Gabow's general matching algorithm. Hash: 85de6860f6b8472baad4c5b063815b18

```
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, bool rev = false) {
```

```cpp
    prev_edge[nedges] = last_edge[a];
    v[nedges] = a;
    w[nedges] = b;
    last_edge[a] = nedges++;

    if(!rev) return g_edge(b, a, true);
}

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 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);
```

```cpp
        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(r != -1 || s != -1) {
                    if(s != -1) swap(r, s);
                    r = first[label[mate[r]]];
                    if(r == -1) continue;
                    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)
```

2.7. **Heavy-light decomposition.** Hash: 097fd70cd19bf3b258d7648f9273bcc1

```cpp
int last_edge[MAXV], prev_edge[MAXE], adj[MAXE], nedges;
int up[MAXV], subtree[MAXV], path[MAXV], offset[MAXV], depth[MAXV];
int nump, numv, psize[MAXV], pfirst[MAXV], walk[MAXV];

struct stree {
    vector<int> data;
    int sz;

    explicit stree(int tsz) : sz(1) {
        while(sz < tsz) sz *= 2;
        data.resize(2*sz);
    }

    int query(int a, int b, int root, int l, int r) {
        if(l == a && r == b) return data[root];
        int mid = (l+r)/2, ans = 0;
        if(a <= mid) ans = max(ans, query(a, min(b, mid), 2*root+1, l, mid));
        if(b > mid) ans = max(ans, query(max(a, mid+1), b, 2*root+2, mid+1, r));
        return ans;
    }
    int query(int a, int b) { return a<=b ? query(a, b, 0, 0, sz-1) : 0; }

    void update(int pos, int val, int root, int l, int r) {
        if(l == r) { data[root] = val; return; }
        int mid = (l+r)/2;
        if(pos <= mid) update(pos, val, 2*root+1, l, mid);
        else update(pos, val, 2*root+2, mid+1, r);
        data[root] = max(data[2*root+1], data[2*root+2]);
    }
    void update(int pos, int val) { update(pos, val, 0, 0, sz-1); }
};

void hl_init(int n) {
    memset(last_edge, -1, sizeof(int) * n);
    nedges = 0;
```

```cpp
            first[c] = r;
        }
        if(done) break;
    }
}
return ret;
}
```

```cpp
}

void hl_edge(int a, int b, bool rev = false) {
    prev_edge[nedges] = last_edge[a];
    adj[nedges] = b;
    last_edge[a] = nedges++;

    if(!rev) hl_edge(b, a, true);
}

vector<stree> segtree;
void heavy_light() {
    memset(up, -1, sizeof up);
    stack<int> s; if(last_edge[0] != -1) s.push(last_edge[0]);

    walk[0] = depth[0] = up[0] = 0; numv = subtree[0] = 1;
    while(!s.empty()) {
        int i = s.top(), v = adj[i^1], w = adj[i];
        if(up[w] == -1) {
            up[w] = v; depth[w] = depth[v]+1; subtree[w] = 1;
            walk[numv++] = w; s.push(last_edge[w]);
        } else {
            s.pop(); if(up[w] == v) subtree[v] += subtree[w];
            if(prev_edge[i] != -1) s.push(prev_edge[i]);
        }
    }

    pfirst[0] = path[0] = offset[0] = 0; nump = psize[0] = 1;
    for(int i = 1; i < numv; i++) {
        int v = walk[i], p = up[v];
        if(2*subtree[v] < subtree[p] || p == 0)
            offset[v] = 0, path[v] = nump, pfirst[nump] = v, psize[nump++] = 1;
        else
            offset[v] = offset[p]+1, path[v] = path[p], psize[path[v]]++;
    }
```

```
    segtree.clear(); segtree.reserve(nump);
    for(int i = 0; i < nump; i++) segtree.push_back(stree(psize[i]));
}

int lca(int v, int w) {
    int fpv = pfirst[path[v]], fpw = pfirst[path[w]];
```

2.8. **Link-cut tree.** Hash: eddb323eb229e5c7bb67a8326d84e371

```
class splay {
public:
    splay *sons[2], *up, *path_up;
    splay() : up(NULL), path_up(NULL) {
        sons[0] = sons[1] = NULL;
    }

    bool is_r(splay* n) {
        return n == sons[1];
    }
};

void rotate(splay* t, bool to_l) {
    splay* n = t->sons[to_l]; swap(t->path_up, n->path_up);
    t->sons[to_l] = n->sons[!to_l]; if(t->sons[to_l]) t->sons[to_l]->up = t;
    n->up = t->up; if(n->up) n->up->sons[n->up->is_r(t)] = n;
    n->sons[!to_l] = t; t->up = n;
}

void do_splay(splay* n) {
    for(splay* p; (p = n->up) != NULL; )
        if(p->up == NULL)
            rotate(p, p->is_r(n));
        else {
            bool dirp = p->is_r(n), dirg = p->up->is_r(p);
            if(dirp == dirg)
                rotate(p->up, dirg), rotate(p, dirp);
            else
                rotate(p, dirp), rotate(n->up, dirg);
        }
}

struct link_cut {
    splay* vtxs;
    link_cut(int numv) { vtxs = new splay[numv]; }
    ~link_cut() { delete[] vtxs; }
```

```
    while(v != 0 && w != 0 && fpv != fpw) {
        if(depth[up[fpv]] > depth[up[fpw]]) swap(v, w), swap(fpv, fpw);
        w = up[fpw]; fpw = pfirst[path[w]];
    }
    return depth[v] < depth[w] ? v : w;
}



    void access(splay* ov) {
        for(splay *w = ov, *v = ov; w != NULL; v = w, w = w->path_up) {
            do_splay(w);
            if(w->sons[1]) w->sons[1]->path_up = w, w->sons[1]->up = NULL;
            if(w != v) w->sons[1] = v, v->up = w, v->path_up = NULL;
            else w->sons[1] = NULL;
        }
        do_splay(ov);
    }

    splay* find(int v) {
        splay* s = &vtxs[v];
        access(s); while(s->sons[0]) s = s->sons[0]; do_splay(s);
        return s;
    }

    void link(int parent, int son) {
        access(&vtxs[son]); access(&vtxs[parent]);
        assert(vtxs[son].sons[0] == NULL);
        vtxs[son].sons[0] = &vtxs[parent];
        vtxs[parent].up = &vtxs[son];
    }

    void cut(int v) {
        access(&vtxs[v]);
        if(vtxs[v].sons[0]) vtxs[v].sons[0]->up = NULL;
        vtxs[v].sons[0] = NULL;
    }

    int lca(int v, int w) {
        access(&vtxs[v]); access(&vtxs[w]); do_splay(&vtxs[v]);
        if(vtxs[v].path_up == NULL) return v;
        return vtxs[v].path_up - vtxs;
    }
};
```

3. MATH

3.1. Fractions. Hash: 85739ae11b5b0351c0a9b5b6f813eaf8

```cpp
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); }
};
```

```cpp
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

```cpp
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);
```

```cpp
    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: 8578a256b2926d8be6ace63e1ed4088c

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

    int sz = 1;
    for(int i = 1; i < seq.size(); ++i) {
        int lo = 0, hi = sz;
```

```cpp
        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[ 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,1); 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: d3bdcc520c56773a81a0a1e5031e999f

```
long double romberg(long double a, long double b,
                long double(*func)(long double)) {
    long double R[16][16], div = (b-a)/2;
```

```
    R[0][0] = div * (func(a) + func(b));
    for(int n = 1; n <= 15; n++, div /= 2) {
        R[n][0] = R[n-1][0]/2;
        for(long double sample = a + div; sample < b; sample += 2 * div)
```

```
        R[n][0] += div * func(a + sample);
    }

    for(int m = 1; m <= 15; m++)
        for(int n = m; n <= 15; n++)
```

```
            R[n][m] = R[n][m-1] + 1/(pow(4, m)-1) * (R[n][m-1] - R[n-1][m-1]);

    return R[15][15];
}
```

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. **Cooley-Tukey's algorithm.** Hash: 2f8e032ae3f77a94dbe8ac547ef8c2b2

```
typedef complex<long double> pt;
pt tmp[1<<20];

void fft(pt *in, int sz, bool inv = false) {
   if(sz == 1) return;
   for(int i = 0; i < sz; i++)
      tmp[i] = in[i];

   sz /= 2;
   pt *even = in, *odd = in + sz;
   for(int i = 0; i < 2*sz; i++)
      if(i&1) odd[i/2] = tmp[i];
      else even[i/2] = tmp[i];
```

```
   fft(even, sz, inv);
   fft(odd, sz, inv);

   long double p = (inv ? 1 : -1) * acosl(-1)/sz;
   for(int i = 0; i < sz; i++) {
      pt conv = pt(cosl(i*p), sinl(i*p)) * odd[i];
      tmp[i] = even[i] + conv;
      tmp[i+sz] = even[i] - conv;
   }

   for(int i = 0; i < 2*sz; i++)
      in[i] = tmp[i];
}
```

3.10. **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 p1p2(half), q1q2(half);
   for(int i = 0; i < half; i++)
      p1p2[i] = p1[i] + p2[i], q1q2[i] = q1[i] + q2[i];

   poly low = mult(p1, q1), high = mult(p2, q2), mid = mult(p1p2, q1q2);
   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;
}
```

3.11. 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];
         }
   }
}
```

3.12. 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);
```

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

```cpp
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;
```

```cpp
    for(int i = 0; i < n; ++i) {
        int i1 = g_mod(i+1, n);
        if (ps_isects(pol[i], pol[i1], p)) return -1;
        else if(((sgn(pol[i].y - p.y) == 1) != (sgn(pol[i1].y - p.y) == 1)) &&
                ccw(pol[i], p, pol[i1]) == sgn(pol[i].y - pol[i1].y)) ++count;
    }
    return count % 2;
}
```

4.4. **Miscellaneous primitives.** Hash: be051245293a9db9c991d414c598e854

```cpp
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);
}
```

```cpp
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

```cpp
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;
```

```cpp
            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

```cpp
pt pivot;
```

```cpp
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]);
```

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);
```

```
    sort(pts.begin() + 1, pts.end(), hull_comp);

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

    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;
}
```

```
    double delta = dist(ret.first, ret.second);

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

4.8. **Kd-tree.** Hash: 181bc30d9b4f2bfc8c42ca71101934ba

```
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 = true) {
    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;

    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(INF, INF) : 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;
}
```

4.9. **Range tree.** Hash: c81f7107969ade9a64ad085c075d8310

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

int rt_recurse(int root, int left, int right) {
    lnk[root][0].clear(); lnk[root][1].clear(); tree[root].clear();

    if(left == right) {
        vector<pt>::iterator it;
        it = lower_bound(pts.begin(), pts.end(), pt(xs[left], -INF));
        for(; it != pts.end() && cmp(it->x, xs[left]) == 0; ++it)
            tree[root].push_back(*it);
        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);

    lnk[root][0].reserve(sz1+sz2+1);
    lnk[root][1].reserve(sz1+sz2+1);
    tree[root].reserve(sz1+sz2);

    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 < sz1 && compy(tree[cl][llink], last))
            ++llink;
        while(rlink < sz2 && 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());
    xs.clear();
    for(int i = 0; i < pts.size(); ++i) xs.push_back(pts[i].x);
    xs.erase(unique(xs.begin(), xs.end()), xs.end());
    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(posl == posr) return 0;
    if(a <= xs[l] && xs[r] <= b)
        return posr - posl;

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

```cpp
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;
}
```

```cpp
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. **Big numbers (PUC-Rio).** Hash: a7d74e7158634f9201c19235badd3364

```cpp
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; }
```

```cpp
    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. **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];
    }
  }
}
```

6.2. **Manacher's algorithm.** Hash: 3dc4ba5a2519725da8ba9ae147d9f8d7

```
vector<int> manacher(const string& s) {
  string s2 = "#";
  for(unsigned int i = 0; i < s.size(); i++)
    s2 += s[i], s2 += '#';

  int c = 1, sz = (int)s2.size(), j;
  vector<int> ans(sz);
  while(c < sz) {
    while(c > ans[c] && c+ans[c]+1 < sz && s2[c-ans[c]-1] == s2[c+ans[c]+1])
      ans[c]++;
```

```
    j = 1;
    while(c+j < sz && j < ans[c]-ans[c-j])
      ans[c+j] = ans[c-j], j++;
    if(c+j < sz)
      ans[c+j] = ans[c]-j;
    c += j;
  }

  return ans;
}
```

6.3. **Kärkkäinen-Sanders' suffix array algorithm.** Hash: f52d447fe031ca31834ce0b3c4c828f9

```cpp
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 m0[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) {
```

```cpp
        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, m0, 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, p0 = sz-1, pret = sz2+sz-1;
    while(prec >= 0 && p0 >= 0)
        if(rec[prec]%3 == 1 && k_cmp(v[m0[p0]], v[rec[prec]],
                            sub[m0[p0]/3], sub[rec[prec]/3+sz]) ||
           rec[prec]%3 == 2 && k_cmp(v[m0[p0]], v[rec[prec]],
                            v[m0[p0]+1], v[rec[prec]+1],
                            sub[m0[p0]/3+sz], sub[rec[prec]/3+1]))
            rec[pret--] = rec[prec--];
        else
            rec[pret--] = m0[p0--];
    if(p0 >= 0) memcpy(&rec[0], m0, sizeof(int) * (p0+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;
}
```

6.4. **Aho-Corasick's algorithm (Shinta).** Hash: a4da9645039910c608ece0f3cf7ae9eb

```
int term[N]; map<char, int> next[N]; int T[N]; int cnt = 1;
void add(string s, int it){
 int node = 0;
 f(i, 0, s.size()){
   char c = s[i];
   if(!next[node].count(c)) term[cnt] = 0, next[node][c] = cnt, cnt++;
   node = next[node][c];
 }
 term[node] = 1 << it;
}
void aho(){
 queue<int> q;
 for(char c = 'a'; c <= 'z'; c++)
   if(next[0].count(c)) q.push(next[0][c]), T[next[0][c]] = 0;
   else next[0][c] = 0;
```

```
 while(!q.empty()){
   int u = q.front(); q.pop();
   for(char c = 'a'; c <= 'z'; c++) if(next[u].count(c)){
     int v = next[u][c];
     int x = T[u];
     while(!next[x].count(c)) x = T[x];
     x = next[x][c];
     T[v] = x;
     q.push(v);
     term[v] |= term[x];
   }
 }
}
```

6.5. **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:

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

A neat manipulation trick is:

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

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 $f\colon N \to X$ are there?

N	X	Any f	Injective	Surjective
dist.	dist.	x^n	$(x)_n$	$x!\left\{{n \atop x}\right\}$
indist.	dist.	$\binom{x+n-1}{n}$	$\binom{x}{n}$	$\binom{n-1}{n-x}$
dist.	indist.	$\left\{{n \atop 1}\right\} + \ldots + \left\{{n \atop x}\right\}$	$[n \le x]$	$\left\{{n \atop k}\right\}$
indist.	indist.	$p_1(n) + \ldots p_x(n)$	$[n \le x]$	$p_x(n)$

Where $\binom{a}{b} = \frac{1}{b!}(a)_b$ 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:

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

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

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

7.14. Centroid of a polygon. The x coordinate of the centroid of a polygon is given by $\frac{1}{3A}\sum_{i=0}^{n-1}(x_i + x_{i+1})(x_i y_{i+1} - x_{i+1}y_i)$, where A is twice the signed area of the polygon.