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# 1 Contest Setup

## 1.1 vimrc

```

1 | set number      " Show line numbers
2 | set mouse=a     " Enable inaction via mouse
3 | set showmatch   " Highlight matching brace
4 | set cursorline  " Show underline
5 | set cursorcolumn " highlight vertical column
6 |
7 | filetype on "enable file detection
8 | syntax on    "syntax highlight
9 |
10 | set autoindent    " Auto-indent new lines
11 | set shiftwidth=4  " Number of auto-indent spaces
12 | set smartindent   " Enable smart-indent
13 | set smarttab      " Enable smart-tabs
14 | set softtabstop=4 " Number of spaces per Tab
15 |
16 | " -----Optional-----
17 |
18 | set undolevels=10000 " Number of undo levels
19 | set scrolloff=5     " Auto scroll
20 |
21 | set hlsearch      " Highlight all search results
22 | set smartcase     " Enable smart-case search
23 | set ignorecase    " Always case-insensitive
24 | set incsearch     " Searches for strings incrementally
25 |
26 | highlight Comment ctermfg=cyan
27 | set showmode
28 |
29 | set encoding=utf-8
30 | set fileencoding=utf-8
31 | set scriptencoding=utf-8

```

## 1.2 bashrc

```

1 | alias g++="g++ -Wall -Wextra -std=c++11 -O2"

```

## 1.3 C++ template

```

1 | #include <bits/stdc++.h>
2 |
3 | using namespace std;
4 |
5 | #define x first
6 | #define y second
7 |
8 | typedef long long int ll;
9 | typedef pair<int, int> ii;
10 |
11 | int main()
12 | {

```

```

13 |     return 0;
14 | }

```

## 1.4 Java template

```

1 | import java.io.*;
2 | import java.util.*;
3 |
4 | public class Main
5 | {
6 |     public static void main(String[] args)
7 |     {
8 |         MyScanner sc = new MyScanner();
9 |         out = new PrintWriter(new BufferedOutputStream(System.out));
10 |         // Start writing your solution here.
11 |
12 |         // Stop writing your solution here.
13 |         out.close();
14 |     }
15 |
16 |     public static PrintWriter out;
17 |
18 |     public static class MyScanner
19 |     {
20 |         BufferedReader br;
21 |         StringTokenizer st;
22 |
23 |         public MyScanner()
24 |         {
25 |             br = new BufferedReader(new InputStreamReader(System.in));
26 |         }
27 |
28 |         boolean hasNext()
29 |         {
30 |             while (st == null || !st.hasMoreElements()) {
31 |                 try {
32 |                     st = new StringTokenizer(br.readLine());
33 |                 } catch (Exception e) {
34 |                     return false;
35 |                 }
36 |             }
37 |             return true;
38 |         }
39 |
40 |         String next()
41 |         {
42 |             if (hasNext())
43 |                 return st.nextToken();
44 |             return null;
45 |         }
46 |
47 |         int nextInt()
48 |         {
49 |             return Integer.parseInt(next());
50 |         }

```

```

51     long nextLong()
52     {
53         return Long.parseLong(next());
54     }
55
56     double nextDouble()
57     {
58         return Double.parseDouble(next());
59     }
60
61     String nextLine()
62     {
63         String str = "";
64         try {
65             str = br.readLine();
66         } catch (IOException e) {
67             e.printStackTrace();
68         }
69         return str;
70     }
71 }
72
73 }

```

#### 1.4.1 Java Issues

1. Random Shuffle before sorting: `Random rnd = new Random(); rnd.nextInt();`
2. Use StringBuilder for large output

## 2 Reminder

1. 隊友的建議，要認真聽！通常隊友的建議都會突破你盲點
2. Read the problem statements carefully. Input and output specifications and constraints are crucial!
3. Estimate the **time complexity** and **memory complexity** carefully.
4. Time penalty is 20 minutes per WA, **don't rush!**
5. Sample test cases must all be tested and passed before every submission!
6. Test the corner cases, such as 0, 1, -1. Test all edge cases of the input specification.
7. Bus error: the code has `scanf, fgets` but have nothing to read! Check if you have early termination but didn't handle it properly.
8. Binary search? 數學算式移項合併後查詢?
9. Two Pointer  $\leftrightarrow$  Binary Search
10. Directed graph connectivity  $\rightarrow$  DFS. Undirected graph  $\rightarrow$  Union Find

## 3 Useful code

### 3.1 Grep Error and Warnings

```
1 | g++ main.cpp 2>&1 | grep -E 'warning|error'
```

### 3.2 Leap year

```
1 | year % 400 == 0 || (year % 4 == 0 && year % 100 != 0)
```

### 3.3 Fast Exponentiation $O(\log(\exp))$

```

1 ll fast_pow(ll base, ll exp, ll mod)
2 {
3     if (exp == 0)
4         return 1LL;
5     ll res = 1;
6     while (exp > 0) {
7         if (exp & 1) {
8             res = ((res % mod) * (base % mod)) % mod;
9         }
10        exp >>= 1;
11        base = (base * base) % mod;
12    }
13    return res;
14 }

```

### 3.4 GCD $O(\log(a + b))$

注意負數的 case!

```

1 ll gcd(ll a, ll b)
2 {
3     return b == 0 ? a : gcd(b, a % b);
4 }

```

### 3.5 Extended Euclidean Algorithm

Bezout identity  $ax + by = \gcd(a, b)$ , where  $\gcd(a, b)$  is the smallest positive integer that can be written as  $ax + by$ , and every integer of the form  $ax + by$  is a multiple of  $\gcd(a, b)$ .

```

1 ll ext_gcd(ll a, ll b, ll &x, ll &y)
2 {
3     if (a == 0) {
4         x = 0;
5         y = 1;
6         return b;
7     }
8
9     ll x1, y1;
10    ll gcd = ext_gcd(b % a, a, x1, y1);
11
12    x = y1 - (b / a) * x1;
13    y = x1;
14
15    return gcd;
16 }

```

### 3.6 Mod Inverse

Case 1  $\gcd(a, m) = 1$ :  $ax + my = \gcd(a, m) = 1$  (use `ext_gcd`)

Case 2  $m$  is prime:  $a^{m-2} \equiv a^{-1} \pmod m$  (use Fermat's little theorem)

### 3.7 Prime Generator

```

1 bool is_prime[N];
2 vector<ll> primes;
3 void init()
4 {
5     fill(is_prime, is_prime + N, true);
6     for (int i = 2; i < N; i++) {
7         if (is_prime[i] == true) {
8             primes.push_back(i);
9             for (int j = i * i; j < N; j += i)
10                 is_prime[j] = false;
11         }
12     }
13 }

```

### 3.8 Binomial Coefficient

```

1 int binomialCoeff(int n, int k)
2 {
3     int res = 1;
4
5     if ( k > n - k ) // Since C(n, k) = C(n, n-k)
6         k = n - k;
7
8     for (int i = 0; i < k; ++i) // n...n-k / 1...k
9     {
10         res *= (n - i);
11         res /= (i + 1);
12     }
13
14     return res;
15 }

```

### 3.9 STL quick reference

#### 3.9.1 Map

```

1 map<T1, T2> m; // iterable
2 void clear();
3 void erase(T1 key);
4 it find(T1 key); // <key, val>
5 void insert(pair<T1, T2> P);
6 T2 &[](T1 key); // if key not in map, new key will be inserted with
   default val
7 it lower_bound(T1 key); // = m.end() if not found, *it = <key, val>
8 it upper_bound(T1 key); // = m.end() if not found, *it = <key, val>

```

#### 3.9.2 Set

```

1 set<T> s; // iterable
2 void clear();
3 size_t count(T val); // number of val in set

```

```

4 void erase(T val);
5 it find(T val); // = s.end() if not found
6 void insert(T val);
7 it lower_bound(T val); // = s.end() if not found, *it = <key, val>
8 it upper_bound(T val); // = s.end() if not found, *it = <key, val>

```

#### 3.9.3 Algorithm

```

1 // return if i is smaller than j
2 comp = [&](const T &i, const T &j) -> bool;
3 vector<T> v;
4 bool any_of(v.begin(), v.end(), [&](const T &i) -> bool);
5 bool all_of(v.begin(), v.end(), [&](const T &i) -> bool);
6 void copy(inp.begin(), inp.end(), out.begin());
7 int count(v.begin(), v.end(), int val); // number of val in v
8 it unique(v.begin(), v.end()); // it - v.begin() = size
9 // after calling, v[nth] will be n-th smallest elem in v
10 void nth_element(v.begin(), nth_it, bin_comp);
11 void merge(in1.begin(), in1.end(), in2.begin(), in2.end(), out.begin(),
   comp);
12 // include union, intersection, difference, symmetric_difference(xor)
13 void set_union(in1.begin(), in1.end(), in2.begin(), in2.end(), out.
   begin(), comp);
14 bool next_permutation(v.begin(), v.end());
15 // v1, v2 need sorted already, whether v1 includes v2
16 bool inclues(v1.begin(), v1.end(), v2.begin(), v2.end());
17 it find(v.begin(), v.end(), T val); // = v.end() if not found
18 it search(v1.begin(), v1.end(), v2.begin(), v2.end());
19 it lower_bound(v.begin(), v.end(), T val);
20 it upper_bound(v.begin(), v.end(), T val);
21 bool binary_search(v.begin(), v.end(), T val); // exist in v ?
22 void sort(v.begin(), v.end(), comp);
23 void stable_sort(v.begin(), v.end(), comp);

```

#### 3.9.4 String

#### 3.9.5 Priority Queue

```

1 bool cmp(ii a, ii b)
2 {
3     if(a.first == b.first)
4         return a.second > b.second;
5     return b.first > a.first;
6 }
7
8 priority_queue< ii, vector<ii>, function<bool(ii, ii)> > pq(cmp);

```

## 4 Search

### 4.1 Binary Search

#### 4.1.1 Find key

#### 4.1.2 Upper / lower Bound

### 4.2 Ternary Search

### 4.3 折半完全列舉

### 4.4 Two-pointer 爬行法

## 5 Basic data structure

### 5.1 1D BIT

```

1 // BIT is 1-based
2 const int MAX_N = 20000; //這個記得改!
3 ll bit[MAX_N + 1];
4
5 int sum(int i) {
6     int s = 0;
7     while (i > 0) {
8         s += bit[i];
9         i -= (i & -i);
10    }
11    return s;
12 }
13
14 void add(int i, int x) {
15     while (i <= MAX_N) {
16         bit[i] += x;
17         i += (i & -i);
18    }
19 }

```

### 5.2 2D BIT

```

1 // BIT is 1-based
2 const int MAX_N = 20000, MAX_M = 20000; //這個記得改!
3 ll bit[MAX_N + 1][MAX_M + 1];
4
5 ll sum(int a, int b) {
6     ll s = 0;
7     for (int i = a; i > 0; i -= (i & -i))
8         for (int j = b; j > 0; j -= (j & -j))
9             s += bit[i][j];
10    return s;
11 }
12
13 void add(int a, int b, ll x) {
14     // MAX_N, MAX_M 須適時調整!
15     for (int i = a; i <= MAX_N; i += (i & -i))

```

```

16     for (int j = b; j <= MAX_M; j += (j & -j))
17         bit[i][j] += x;
18 }

```

### 5.3 Union Find

```

1 #define N 20000 // 記得改
2 struct UFDS {
3     int par[N];
4
5     void init() {
6         memset(par, -1, sizeof(par));
7     }
8
9     int root(int x) {
10        return par[x] < 0 ? x : par[x] = root(par[x]);
11    }
12
13    void merge(int x, int y) {
14        x = root(x);
15        y = root(y);
16
17        if (x != y) {
18            if (par[x] > par[y])
19                swap(x, y);
20            par[x] += par[y];
21            par[y] = x;
22        }
23    }
24 }

```

### 5.4 Segment Tree

### 5.5 Sparse Table

```

1 struct {
2     int sp[MAX_LOG_N][MAX_N]; // MAX_LOG_N = ceil(lg(MAX_N))
3
4     void build(int inp[], int n) {
5         for (int j = 0; j < n; j++) {
6             sp[0][j] = inp[j];
7         }
8
9         for (int i = 1; (1 << i) <= n; i++)
10            for (int j = 0; j + (1 << i) <= n; j++)
11                sp[i][j] =
12                    min(sp[i - 1][j], sp[i - 1][j + (1 << (i - 1))]);
13    }
14
15    int query(int l, int r) { // [l, r)
16        int k = floor(log2(r - l));
17
18        return min(sp[k][l], sp[k][r - (1 << k)]);
19    }
20 } sptb;

```

## 6 Dynamic Programming

## 7 Tree

### 7.1 LCA

## 8 Graph

### 8.1 Articulation point / edge

### 8.2 CC

#### 8.2.1 BCC vertex

#### 8.2.2 BCC edge

#### 8.2.3 SCC

### 8.3 Shortest Path

#### 8.3.1 Dijkstra

#### 8.3.2 Dijkstra (next-to-shortest path)

#### 8.3.3 SPFA

#### 8.3.4 Bellman-Ford

#### 8.3.5 Floyd-Warshall

### 8.4 Kruskal MST

### 8.5 Flow

#### 8.5.1 Max Flow (Dinic)

#### 8.5.2 Min-Cut

#### 8.5.3 Min Cost Max Flow

#### 8.5.4 Maximum Bipartite Graph

## 9 String

### 9.1 KMP

### 9.2 Z Algorithm

### 9.3 Trie

### 9.4 Suffix Array

## 10 Geometry

### 10.1 Template

```

1 // C++ routines for computational geometry.
2
3 #include <cassert>
4 #include <cmath>
5 #include <iostream>
6 #include <vector>
7
8 using namespace std;
9
10 double INF = 1e100;
11 double EPS = 1e-12;
12
13 struct PT {
14     double x, y;
15     PT() {}
16     PT(double x, double y) : x(x), y(y) {}
17     PT(const PT &p) : x(p.x), y(p.y) {}
18     PT operator+(const PT &p) const
19     {
20         return PT(x + p.x, y + p.y);
21     }
22     PT operator-(const PT &p) const
23     {
24         return PT(x - p.x, y - p.y);
25     }
26     PT operator*(double c) const
27     {
28         return PT(x * c, y * c);
29     }
30     PT operator/(double c) const
31     {
32         return PT(x / c, y / c);
33     }
34 };
35
36 double dot(PT p, PT q)
37 {
38     return p.x * q.x + p.y * q.y;
39 }
40 double dist2(PT p, PT q)
41 {
42     return dot(p - q, p - q);
43 }
44 double cross(PT p, PT q)
45 {
46     return p.x * q.y - p.y * q.x;
47 }
48 ostream &operator<<(ostream &os, const PT &p)
49 {
50     os << "(" << p.x << ", " << p.y << ")";
51 }
52
53 // rotate a point CCW or CW around the origin
54 PT RotateCCW90(PT p)
55 {
56     return PT(-p.y, p.x);

```

```

57 }
58 PT RotateCW90(PT p)
59 {
60     return PT(p.y, -p.x);
61 }
62 PT RotateCCW(PT p, double t)
63 {
64     return PT(p.x * cos(t) - p.y * sin(t), p.x * sin(t) + p.y * cos(t));
65 }
66 // project point c onto line through a and b
67 // assuming a != b
68 PT ProjectPointLine(PT a, PT b, PT c)
69 {
70     return a + (b - a) * dot(c - a, b - a) / dot(b - a, b - a);
71 }
72 // project point c onto line segment through a and b
73 PT ProjectPointSegment(PT a, PT b, PT c)
74 {
75     double r = dot(b - a, b - a);
76     if (fabs(r) < EPS)
77         return a;
78     r = dot(c - a, b - a) / r;
79     if (r < 0)
80         return a;
81     if (r > 1)
82         return b;
83     return a + (b - a) * r;
84 }
85 // compute distance from c to segment between a and b
86 double DistancePointSegment(PT a, PT b, PT c)
87 {
88     return sqrt(dist2(c, ProjectPointSegment(a, b, c)));
89 }
90 // compute distance between point (x,y,z) and plane ax+by+cz=d
91 double DistancePointPlane(double x, double y, double z, double a,
92     double b,
93     double c, double d)
94 {
95     return fabs(a * x + b * y + c * z - d) / sqrt(a * a + b * b + c * c);
96 }
97 // determine if lines from a to b and c to d are parallel or collinear
98 bool LinesParallel(PT a, PT b, PT c, PT d)
99 {
100     return fabs(cross(b - a, c - d)) < EPS;
101 }
102 bool LinesCollinear(PT a, PT b, PT c, PT d)
103 {

```

```

104     return LinesParallel(a, b, c, d) && fabs(cross(a - b, a - c)) < EPS
105         &&
106             fabs(cross(c - d, c - a)) < EPS;
107 }
108 // determine if line segment from a to b intersects with
109 // line segment from c to d
110 bool SegmentsIntersect(PT a, PT b, PT c, PT d)
111 {
112     if (LinesCollinear(a, b, c, d)) {
113         if (dist2(a, c) < EPS || dist2(a, d) < EPS || dist2(b, c) < EPS
114             ||
115                 dist2(b, d) < EPS)
116             return true;
117         if (dot(c - a, c - b) > 0 && dot(d - a, d - b) > 0 && dot(c - b,
118             d - b) > 0)
119             return false;
120         return true;
121     }
122     if (cross(d - a, b - a) * cross(c - a, b - a) > 0)
123         return false;
124     if (cross(a - c, d - c) * cross(b - c, d - c) > 0)
125         return false;
126     return true;
127 }
128 // compute intersection of line passing through a and b
129 // with line passing through c and d, assuming that unique
130 // intersection exists; for segment intersection, check if
131 // segments intersect first
132 PT ComputeLineIntersection(PT a, PT b, PT c, PT d)
133 {
134     b = b - a;
135     d = c - d;
136     c = c - a;
137     assert(dot(b, b) > EPS && dot(d, d) > EPS);
138     return a + b * cross(c, d) / cross(b, d);
139 }
140 // compute center of circle given three points
141 PT ComputeCircleCenter(PT a, PT b, PT c)
142 {
143     b = (a + b) / 2;
144     c = (a + c) / 2;
145     return ComputeLineIntersection(b, b + RotateCW90(a - b), c,
146         c + RotateCW90(a - c));
147 }
148 // determine if point is in a possibly non-convex polygon (by William
149 // Randolph Franklin); returns 1 for strictly interior points, 0 for
150 // strictly exterior points, and 0 or 1 for the remaining points.
151 // Note that it is possible to convert this into an *exact* test using
152 // integer arithmetic by taking care of the division appropriately
153 // (making sure to deal with signs properly) and then by writing exact
154 // tests for checking point on polygon boundary
155 bool PointInPolygon(const vector<PT> &p, PT q)

```

```

162 {
163     bool c = 0;
164     for (int i = 0; i < p.size(); i++) {
165         int j = (i + 1) % p.size();
166         if ((p[i].y <= q.y && q.y < p[j].y || p[j].y <= q.y && q.y < p[
167             i].y) &&
168             q.x < p[i].x + (p[j].x - p[i].x) * (q.y - p[i].y) / (p[j].y
169                 - p[i].y))
170             c = !c;
171     }
172     return c;
173 }
174 // determine if point is on the boundary of a polygon
175 bool PointOnPolygon(const vector<PT> &p, PT q)
176 {
177     for (int i = 0; i < p.size(); i++)
178         if (dist2(ProjectPointSegment(p[i], p[(i + 1) % p.size()], q),
179             q) < EPS)
180             return true;
181     return false;
182 }
183 // compute intersection of line through points a and b with
184 // circle centered at c with radius r > 0
185 vector<PT> CircleLineIntersection(PT a, PT b, PT c, double r)
186 {
187     vector<PT> ret;
188     b = b - a;
189     a = a - c;
190     double A = dot(b, b);
191     double B = dot(a, b);
192     double C = dot(a, a) - r * r;
193     double D = B * B - A * C;
194     if (D < -EPS)
195         return ret;
196     ret.push_back(c + a + b * (-B + sqrt(D + EPS)) / A);
197     if (D > EPS)
198         ret.push_back(c + a + b * (-B - sqrt(D)) / A);
199     return ret;
200 }
201 // compute intersection of circle centered at a with radius r
202 // with circle centered at b with radius R
203 vector<PT> CircleCircleIntersection(PT a, PT b, double r, double R)
204 {
205     vector<PT> ret;
206     double d = sqrt(dist2(a, b));
207     if (d > r + R || d + min(r, R) < max(r, R))
208         return ret;
209     double x = (d * d - R * R + r * r) / (2 * d);
210     double y = sqrt(r * r - x * x);
211     PT v = (b - a) / d;
212     ret.push_back(a + v * x + RotateCCW90(v) * y);
213     if (y > 0)
214         ret.push_back(a + v * x - RotateCCW90(v) * y);

```

```

215     return ret;
216 }
217 // This code computes the area or centroid of a (possibly nonconvex)
218 // polygon, assuming that the coordinates are listed in a clockwise or
219 // counterclockwise fashion. Note that the centroid is often known as
220 // the "center of gravity" or "center of mass".
221 double ComputeSignedArea(const vector<PT> &p)
222 {
223     double area = 0;
224     for (int i = 0; i < p.size(); i++) {
225         int j = (i + 1) % p.size();
226         area += p[i].x * p[j].y - p[j].x * p[i].y;
227     }
228     return area / 2.0;
229 }
230 double ComputeArea(const vector<PT> &p)
231 {
232     return fabs(ComputeSignedArea(p));
233 }
234 PT ComputeCentroid(const vector<PT> &p)
235 {
236     PT c(0, 0);
237     double scale = 6.0 * ComputeSignedArea(p);
238     for (int i = 0; i < p.size(); i++) {
239         int j = (i + 1) % p.size();
240         c = c + (p[i] + p[j]) * (p[i].x * p[j].y - p[j].x * p[i].y);
241     }
242     return c / scale;
243 }
244 // tests whether or not a given polygon (in CW or CCW order) is simple
245 bool IsSimple(const vector<PT> &p)
246 {
247     for (int i = 0; i < p.size(); i++) {
248         for (int k = i + 1; k < p.size(); k++) {
249             int j = (i + 1) % p.size();
250             int l = (k + 1) % p.size();
251             if (i == l || j == k)
252                 continue;
253             if (SegmentsIntersect(p[i], p[j], p[k], p[l]))
254                 return false;
255         }
256     }
257     return true;
258 }
259 int main()
260 {
261     // expected: (-5,2)
262     cerr << RotateCCW90(PT(2, 5)) << endl;
263     // expected: (5,-2)

```



```

271 cerr << RotateCW90(PT(2, 5)) << endl;
272
273 // expected: (-5,2)
274 cerr << RotateCCW(PT(2, 5), M_PI / 2) << endl;
275
276 // expected: (5,2)
277 cerr << ProjectPointLine(PT(-5, -2), PT(10, 4), PT(3, 7)) << endl;
278
279 // expected: (5,2) (7.5,3) (2.5,1)
280 cerr << ProjectPointSegment(PT(-5, -2), PT(10, 4), PT(3, 7)) << " "
281 << ProjectPointSegment(PT(7.5, 3), PT(10, 4), PT(3, 7)) << " "
282 << ProjectPointSegment(PT(-5, -2), PT(2.5, 1), PT(3, 7)) <<
endl;
283
284 // expected: 6.78903
285 cerr << DistancePointPlane(4, -4, 3, 2, -2, 5, -8) << endl;
286
287 // expected: 1 0 1
288 cerr << LinesParallel(PT(1, 1), PT(3, 5), PT(2, 1), PT(4, 5)) << "
"
289 << LinesParallel(PT(1, 1), PT(3, 5), PT(2, 0), PT(4, 5)) << "
"
290 << LinesParallel(PT(1, 1), PT(3, 5), PT(5, 9), PT(7, 13)) <<
endl;
291
292 // expected: 0 0 1
293 cerr << LinesCollinear(PT(1, 1), PT(3, 5), PT(2, 1), PT(4, 5)) << "
"
294 << LinesCollinear(PT(1, 1), PT(3, 5), PT(2, 0), PT(4, 5)) << "
"
295 << LinesCollinear(PT(1, 1), PT(3, 5), PT(5, 9), PT(7, 13)) <<
endl;
296
297 // expected: 1 1 1 0
298 cerr << SegmentsIntersect(PT(0, 0), PT(2, 4), PT(3, 1), PT(-1, 3))
<< " "
299 << SegmentsIntersect(PT(0, 0), PT(2, 4), PT(4, 3), PT(0, 5))
<< " "
300 << SegmentsIntersect(PT(0, 0), PT(2, 4), PT(2, -1), PT(-2, 1))
<< " "
301 << SegmentsIntersect(PT(0, 0), PT(2, 4), PT(5, 5), PT(1, 7))
<< endl;
302
303 // expected: (1,2)
304 cerr << ComputeLineIntersection(PT(0, 0), PT(2, 4), PT(3, 1), PT
(-1, 3))
305 << endl;
306
307 // expected: (1,1)
308 cerr << ComputeCircleCenter(PT(-3, 4), PT(6, 1), PT(4, 5)) << endl;
309
310 vector<PT> v;
311 v.push_back(PT(0, 0));
312 v.push_back(PT(5, 0));
313 v.push_back(PT(5, 5));
314 v.push_back(PT(0, 5));

```

```

315 // expected: 1 1 1 0 0
316 cerr << PointInPolygon(v, PT(2, 2)) << " " << PointInPolygon(v, PT
(2, 0))
317 << " " << PointInPolygon(v, PT(0, 2)) << " "
318 << PointInPolygon(v, PT(5, 2)) << " " << PointInPolygon(v, PT
(2, 5))
319 << endl;
320
321 // expected: 0 1 1 1 1
322 cerr << PointOnPolygon(v, PT(2, 2)) << " " << PointOnPolygon(v, PT
(2, 0))
323 << " " << PointOnPolygon(v, PT(0, 2)) << " "
324 << PointOnPolygon(v, PT(5, 2)) << " " << PointOnPolygon(v, PT
(2, 5))
325 << endl;
326
327 // expected: (1,6)
328 // (5,4) (4,5)
329 // blank line
330 // (4,5) (5,4)
331 // blank line
332 // (4,5) (5,4)
333 vector<PT> u = CircleLineIntersection(PT(0, 6), PT(2, 6), PT(1, 1),
5);
334 for (int i = 0; i < u.size(); i++)
335 cerr << u[i] << " ";
336 cerr << endl;
337 u = CircleLineIntersection(PT(0, 9), PT(9, 0), PT(1, 1), 5);
338 for (int i = 0; i < u.size(); i++)
339 cerr << u[i] << " ";
340 cerr << endl;
341 u = CircleCircleIntersection(PT(1, 1), PT(10, 10), 5, 5);
342 for (int i = 0; i < u.size(); i++)
343 cerr << u[i] << " ";
344 cerr << endl;
345 u = CircleCircleIntersection(PT(1, 1), PT(8, 8), 5, 5);
346 for (int i = 0; i < u.size(); i++)
347 cerr << u[i] << " ";
348 cerr << endl;
349 u = CircleCircleIntersection(PT(1, 1), PT(4.5, 4.5), 10, sqrt(2.0)
/ 2.0);
350 for (int i = 0; i < u.size(); i++)
351 cerr << u[i] << " ";
352 cerr << endl;
353 u = CircleCircleIntersection(PT(1, 1), PT(4.5, 4.5), 5, sqrt(2.0) /
2.0);
354 for (int i = 0; i < u.size(); i++)
355 cerr << u[i] << " ";
356 cerr << endl;
357
358 // area should be 5.0
359 // centroid should be (1.1666666, 1.1666666)
360 PT pa[] = {PT(0, 0), PT(5, 0), PT(1, 1), PT(0, 5)};
361 vector<PT> p(pa, pa + 4);
362 PT c = ComputeCentroid(p);
363

```

```

364 cerr << "Area: " << ComputeArea(p) << endl;
365 cerr << "Centroid: " << c << endl;
366
367 return 0;
368 }

```

=====

```

1 #define x first
2 #define y second
3 typedef pair <double , double > pt;
4 struct line {
5     double a, b, c;
6     // coefficients in general form, compare up to constant factor
7 }

```

```

8 pt operator-(pt u, pt v) { return pt(u.x-v.x, u.y-v.y); }
9 pt operator+(pt u, pt v) { return pt(u.x+v.x, u.y+v.y); }
10 pt operator*(pt u, double d) { return pt(u.x*d, u.y*d); }
11 double operator*(pt u, pt v) { return u.x*v.x + u.y*v.y; } // dot
    product double operator!(pt p) { return sqrt(p*p); } // norm
12 double operator^(pt u, pt v) { return u.x*v.y - u.y*v.x; } // cross
    product

```

### 10.1.1 Point / Line

### 10.1.2 Intersection

## 10.2 Half-plane intersection

### 10.3 Convex Hull