CSN-520

# REPORT TITLE

## CODING PROJECT-2

GroupID: 26

| | |
|---|---|
| Ambar Zaidi | 14114009 |
| Tarun Kumar | 14114068 |

# Objective

To know implementation of different Computational Geometry algorithms for solving the Art-Gallery Problem.

### Problem Statement of CP-2:

### 1.

- Construct a simple polygon with n vertices. Your program should be able to take n as input (e.g., 20 or 100) from the user, then randomly generate n distinct points with x and y coordinates in 2D geometry.

  Store the simple polygon using the required data structure DCEL.

### Method

- Take the input value of 'n'
- Generate 'n' random points in cartesian plane
- Generate a random simple polygon with 'n' vertices
- Store it as DCEL

## DCEL Data Structure implementation

Classes created:

- Point
- Edge
- Face
- DCEL

Classes also contain some helper functions.

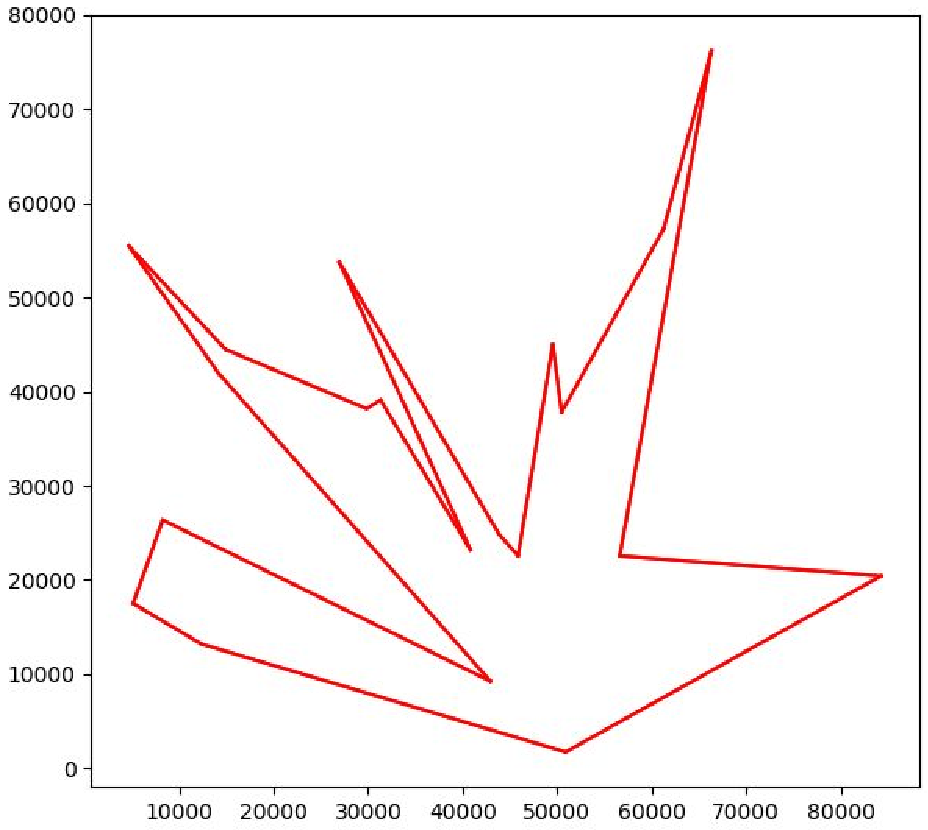
buildSimplePolygon() can be used to create a polygon from a given polygon boundary,

```
class Point:
        def __init__(self, coordinates,auxData=None):
                self.data=auxData
                self.coords = coordinates
                self.edge = None
                self.ear = False
                self.next = None
                self.prev = None
                self.color= -1

        def ___str___(self):
                return str(self.ID)
        def __getitem__(self,key):
                return self.coords[key]
        def scale(self, k1, k2):
                self.coords = list(self.coords)
                self.coords[0] = int(self.coords[0] * k1)
                self.coords[1] = int(self.coords[1] * k2)
                self.coords = tuple(self.coords)
        def __hash__(self):
                return hash(id(self))
        def getData(self):
                return self.data
        def setData(self, auxData):
                self.data = auxData
        def getCoords(self):
                return Point(self.coords)
        def setCoords(self):
                self.coords = coordinates
        def getOutgoingEdges(self):
                visited = set()
                out = []
                here = self.edge
                while here and here not in visited:
                    out.append(here)
                    visited.add(here)
                    temp = here.getTwin()
                    if temp:
                    here = temp.getNext()
                    else:
                    here = None
                return out
        def getIncidentEdge(self):
                return self.edge
        def setIncidentEdge(self, edge):
                self.edge = edge
        def __repr__(self):
                return 'DCEL.Point with coordnates (' +
        str(self.coords[0])+','+str(self.coords[1])+')'


class Edge:
        def __init__(self, auxData=None):
                self.data = auxData
                self.twin = None
                self.origin = None
                self.face = None
                self.next = None
                self.prev = None
        def __hash__(self):
                return hash(id(self))
        def getTwin(self):
                return self.twin
        def setTwin(self, twin):
                self.twin = twin
        def getData(self):
                return self.data
        def setData(self, auxData):
                self.data = auxData
        def getNext(self):
                return self.next
        def setNext(self, edge):
                self.next = edge
        def getOrigin(self):
                return self.origin
        def setOrigin(self, v):
                self.origin = v
        def getPrev(self):
                return self.prev
        def setPrev(self, edge):
                self.prev = edge
        def getDest(self):
                return self.twin.origin
        def getFace(self):
                return self.face
        def getFaceBoundary(self):
                visited = set()
                bound = []
                here = self
                while here and here not in visited:
                    bound.append(here)
                    visited.add(here)
                    here = here.getNext()
                return bound
        def setFace(self, face):
                self.face = face
        def clone(self):
                c = Edge()
                c.data,c.twin,c.origin,c.face,c.next,c.prev =
        self.data,self.twin,self.origin,self.face,self.next,self.prev
        def __repr__(self):
                return 'DCEL.Edge from Origin: DCEL.Point with coordinates (' +
        str(self.getOrigin().coords[0])+','+str(self.getOrigin().coords[1])+')' +
        '\nDestination: DCEL.Point with coordinates (' +
        str(self.getDest().coords[0])+','+str(self.getDest().coords[1])+')'

class Face:
        def __init__(self, auxData=None):
                self.data = auxData
                self.outer = None
                self.inner = set()
                self.isolated = set()
        def __hash__(self):
                return hash(id(self))
        def getOuterComponent(self):
                return self.outer
        def setOuterComponent(self, edge):
                self.outer = edge
        def getData(self):
                return self.data
        def setData(self, auxData):
                self.data = auxData
        def getOuterBoundary(self):
                if self.outer:
                    return self.outer.getFaceBoundary()
                else:
                    return []
        def getOuterBoundaryCoords(self):
                original_pts = self.getOuterBoundary()
                return [x.origin.coords for x in original_pts]
        def getInnerComponents(self):
                return list(self.inner)
        def addInnerComponent(self, edge):
                self.inner.add(edge)
        def removeInnerComponent(self, edge):
                self.inner.discard(edge)
        def removeIsolatedVertex(self,Point):
                self.isolated.discard(Point)
        def getIsolatedVertices(self):
                return list(self.isolated)
        def addIsolatedVertex(self,Point):
                self.isolated.add(Point)

class DCEL:
        def __init__(self):
                self.exterior = Face()
        def getExteriorFace(self):
                return self.exterior
        def getFaces(self):
                result = []
                known = set()
                temp = []
                temp.append(self.exterior)
                known.add(self.exterior)
                while temp:
                        f = temp.pop(0)
                        result.append(f)
                        for e in f.getOuterBoundary():
                        nb = e.getTwin().getFace()
                        if nb and nb not in known:
                                known.add(nb)
                                temp.append(nb)
                        for inner in f.getInnerComponents():
                        for e in inner.getFaceBoundary():
                                nb = e.getTwin().getFace()
                                if nb and nb not in known:
                                        known.add(nb)
                                        temp.append(nb)
                return result

        def getEdges(self):
                edges = set()
                for f in self.getFaces():
                        edges.update(f.getOuterBoundary())
                        for inner in f.getInnerComponents():
                        edges.update(inner.getFaceBoundary())
                return edges

        def getVertices(self):
                verts = set()
                for f in self.getFaces():
                        verts.update(f.getIsolatedVertices())
                        verts.update([e.getOrigin() for e in f.getOuterBoundary()])
                        for inner in f.getInnerComponents():
                        verts.update([e.getOrigin() for e in inner.getFaceBoundary()])
                return verts


def buildSimplePolygon(points):
        d = DCEL()
        if points:
```

```
        exterior = d.getExteriorFace()
        interior = Face()
        verts = []
        for p in points:
            verts.append(Point(p))
        innerEdges = []
        outerEdges = []
        for i in range(len(verts)):
            e = Edge()
            e.setOrigin(verts[i])
            verts[i].setIncidentEdge(e)
            e.setFace(interior)
            t = Edge()
            t.setOrigin(verts[(i+1)%len(verts)])
            t.setFace(exterior)
            t.setTwin(e)
            e.setTwin(t)
            innerEdges.append(e)
            outerEdges.append(t)

        for i in range(len(verts)):
            innerEdges[i].setNext(innerEdges[(i+1)%len(verts)])
            innerEdges[i].setPrev(innerEdges[i-1])
            outerEdges[i].setNext(outerEdges[i-1])
            outerEdges[i].setPrev(outerEdges[(i+1)%len(verts)])
        interior.setOuterComponent(innerEdges[0])
        exterior.addInnerComponent(outerEdges[0])
    return d
```

## Screenshots:

I. N = 20



- Perform Trapezoidalization of the simple polygon you obtained.
- Store the information in the required data structure. Obtain monotone partitions from the trapezoidalization of the simple polygon. Implement the line-sweep (plane-sweep) algorithm to obtain monotone partitions of the n-gon.

## Implementation

```
# divide polygon in two // insert diagonal
def insertDgnl(d, p1, p2):
      if DEBUG:
      print "Inserting diagonal: ",p1,p2
      pointlist1 = []
      pointlist2 = []
      original_pts = d.getFaces()[1].getOuterBoundaryCoords()
      if (p1 in original_pts and p2 in original_pts) and p1!=p2:
      tmp1 = min(original_pts.index(p1), original_pts.index(p2))
      tmp2 = max(original_pts.index(p1), original_pts.index(p2))
      pointlist1 = original_pts[tmp1:(tmp2+1)]
      pointlist2 = original_pts[tmp2:]+original_pts[:(tmp1+1)]
      d1 = buildSimplePolygon(pointlist1)
      d2 = buildSimplePolygon(pointlist2)
      return [d1,d2]
      return [d]

# divide polygon in many // insert list of diagonals
def insertDgnls(d, dgnls):
      ngons = [d]
      while dgnls != []:
      nxt = dgnls.pop(0)
      print "Current dgnl:",nxt
      ngons = [insertDgnl(x, nxt[0], nxt[1]) for x in ngons]
      ngons = [ngon for lngon in ngons for ngon in lngon]
      print len(ngons)
      return ngons

class trapEdge(object):
      def __init__(self,a,b,s,l,r):
      self.left = a
      self.right = b
      self.pivot = s
      self.le = l
      self.re = r

class point(object):
      def __init__(self, a, b):
      self.x = a
      self.y = b

def onSegment(p,q,r):
      if (q.x <= max(p.x, r.x) and q.x >= min(p.x, r.x) and q.y <= max(p.y,
r.y) and q.y >= min(p.y, r.y)):
      return True
      return False
def orientation(p,q,r):
      val = (q.y - p.y) * (r.x - q.x) -(q.x - p.x) * (r.y - q.y)
      if (val == 0):
      return 0
      if(val>0):
      return 1
      return 2
def doIntersect(p1,q1,p2,q2):
      o1 = orientation(p1, q1, p2);
      o2 = orientation(p1, q1, q2);
      o3 = orientation(p2, q2, p1);
      o4 = orientation(p2, q2, q1);
      A,B,C,D = p1,q1,p2,q2
      a1 = B.y - A.y
      b1 = A.x - B.x
      c1 = a1*(A.x) + b1*(A.y)
      a2 = D.y - C.y
      b2 = C.x - D.x
      c2 = a2*(C.x)+ b2*(C.y)
      determinant = a1*b2 - a2*b1
      if(determinant == 0):
      return False
      if (o1 != o2 and o3 != o4):
      return True
      if (o1 == 0 and onSegment(p1, p2, q1)):
      return True
      if (o2 == 0 and onSegment(p1, q2, q1)):
      return True
      if (o3 == 0 and onSegment(p2, p1, q2)):
      return True
      if (o4 == 0 and onSegment(p2, q1, q2)):
      return True
      return False

def findIt(A,B,C,D):
      a1 = B.y - A.y
      b1 = A.x - B.x
      c1 = a1*(A.x) + b1*(A.y)
      a2 = D.y - C.y
      b2 = C.x - D.x
      c2 = a2*(C.x)+ b2*(C.y)
      determinant = a1*b2 - a2*b1
      x = (b2*c1 - b1*c2)/determinant
      y = (a1*c2 - a2*c1)/determinant
      return (x, y)

def findIntersections(lines, hlines):
      res = {}
      for hline in hlines:
      p1 = point(hline[0],hline[1])
      q1 = point(hline[2],hline[3])
      for line in lines:
            p2 = point(line[0][0],line[0][1])
            q2 = point(line[0][2],line[0][3])
            if(doIntersect(p1,q1,p2,q2)):
            res[findIt(p1,q1,p2,q2)] = line[1]
      return res

def getTrapEdges(d):
      N = len(d.getVertices())
      verts = [ list(d.getVertices())[i].coords for i in range(N) ]
      verts = zip(verts, [i for i in list(d.getVertices())])
      edges = [(verts[i][1].next.coords,verts[i][1].coords) for i in range(N)
]
      edges = zip(edges, [v[1].getOutgoingEdges()[0] for v in verts])
      verts.sort(key=lambda x: -x[0][0])
      lines = []
      temp = []
      for e in edges:
      temp = [e[0][0][0],e[0][0][1],e[0][1][0],e[0][1][1]],e[1]
      lines.append(temp)
      lines2 = []
      temp = []
      for v in verts:
      temp = verts[0][0][0],v[0][1],verts[-1][0][0],v[0][1]
      lines2.append(temp)
      res = findIntersections(lines,lines2)

      res = [[x,y,res[(x,y)]] for (x,y) in res]
      res.sort(key = lambda x: -x[1])
      ret = []

      for v in verts:
      templ = [(x[0],x[1],x[2]) for x in res if (x[0]<v[0][0] and
x[1]==v[0][1])]
      tempr = [(x[0],x[1],x[2]) for x in res if (x[0]>v[0][0] and
x[1]==v[0][1])]
      templ.sort(key = lambda x: x[0])
      tempr.sort(key = lambda x: x[0])
      if( len(templ)%2==0 and len(tempr)%2==0 ):
            if v[1].getOutgoingEdges()[0].getTwin().origin.coords[1] <
v[1].coords[1] :
```

```
            tr =
trapEdge(v[0],v[0],v[1],v[1].getOutgoingEdges()[0],v[1].getOutgoingEdges()[1].
getTwin())
            else:
            tr =
trapEdge(v[0],v[0],v[1],v[1].getOutgoingEdges()[1],v[1].getOutgoingEdges()[0])
#                  tr = trapEdge(v[0],v[0],v[1],None,None)
            ret.append(tr)
      if( len(templ)%2==1 and len(tempr)%2==1 ):
            tr =
trapEdge(templ[-1][:2],tempr[0][:2],v[1],templ[-1][2],tempr[0][2])
            ret.append(tr)
      if( len(templ)%2==0 and len(tempr)%2==1 ):
            tr = trapEdge(v[0],tempr[0][:2],v[1],v[1].getOutgoingEdges()[0],
tempr[0][2])
            ret.append(tr)
      if( len(templ)%2==1 and len(tempr)%2==0 ):
            tr =
trapEdge(templ[-1][:2],v[0],v[1],templ[-1][2],v[1].getOutgoingEdges()[1].getTw
in())
            ret.append(tr)

      return ret
# returns list of diagonals for partioning
def monotonePartitioningDgnls(d):

      ret = getTrapEdges(d)
      ret = sorted(ret, key=lambda x:-x.pivot.coords[1])

      a = dict()
      b = dict()

      for x in ret:
      x.re = x.re.getTwin()
      if DEBUG:
            print "\n",x.left,x.right
            print "Pivot:",x.pivot.coords
            print
"Ledge:",x.le.origin.coords,"-->",x.le.getTwin().origin.coords
            print
"Redge:",x.re.origin.coords,"-->",x.re.getTwin().origin.coords


      if x.pivot.coords[1] > x.re.getTwin().origin.coords[1]:
            a[x.pivot] = (x.le,x.re)
            if x.le in b:
            b[x.le].append(x.pivot)
            else:
            b[x.le] = [x.pivot]

            if x.re in b:
            b[x.re].append(x.pivot)
            else:
```

```
            b[x.re] = [x.pivot]

#           if (x.pivot.getOutgoingEdges()[0].getTwin().origin.coords[1] <
x.pivot.coords[1] and
#                 x.pivot.getOutgoingEdges()[1].getTwin().origin.coords[1] <
x.pivot.coords[1] and
#                 x.pivot != x.le.origin ): # split vertex

#                 lc = x.pivot.getOutgoingEdges()[1]
#                 rc = x.pivot.getOutgoingEdges()[0]

#                 a.append((x.le,lc))
#                 a.append((rc,x.re))



# #               if lc in b:
# #                     b[lc].append(x.pivot)
# #               else:
# #                     b[lc] = [x.pivot]

# #               if rc in b:
# #                     b[rc].append(x.pivot)
# #               else:
# #                     b[rc] = [x.pivot]



      for e in b:
      b[e].append(e.getTwin().origin)

      if DEBUG:
      print "\n### a"
      for (i,x) in enumerate(a):
            print
            print i,x.coords
            for e in a[x]:
            print e.origin.coords, e.getTwin().origin.coords

      print "\n### b"
      for (i,x) in enumerate(b):
            print
            print i,x.origin.coords, x.getTwin().origin.coords
            print b[x]

      dgnls = []
      # pt = list(a.keys())[1]

      # print "]]]]",pt.coords
      # print a[pt]
      # print [x.coords for x in b[a[pt][0]] ],b[a[pt][0]].index(pt)
      # print [x.coords for x in b[a[pt][1]] ],b[a[pt][1]].index(pt),"[[[[["
      for pt in sorted(a, key=lambda x:-x.coords[1]):
      if DEBUG:
            print "\n]]]]",pt.coords
            print a[pt][0].origin.coords, a[pt][0].getTwin().origin.coords,
            print len(b[a[pt][0]]),[x.coords for x in b[a[pt][0]]
],b[a[pt][0]].index(pt)
            print a[pt][1].origin.coords, a[pt][1].getTwin().origin.coords,
            print len(b[a[pt][1]]),[x.coords for x in b[a[pt][1]]
],b[a[pt][1]].index(pt),"[[[[["

#     if not a[pt][0].origin == a[pt][1].origin:
#           print "in"
      if pt in ( a[pt][0].origin, a[pt][0].getTwin().origin ):
            dgnls.append((pt, b[a[pt][1]][b[a[pt][1]].index(pt)+1] ))
      elif pt in ( a[pt][1].origin, a[pt][1].getTwin().origin ):
            dgnls.append((pt, b[a[pt][0]][b[a[pt][0]].index(pt)+1] ))
      else:
            dgnls.append((pt,
                        min( b[a[pt][0]][b[a[pt][0]].index(pt)+1],
                              b[a[pt][1]][b[a[pt][1]].index(pt)+1],
                              key=lambda x:x.coords[1]
                              )
                        ))
      if DEBUG:
            print "Dgnls:",[(x[0].coords,x[1].coords) for x in dgnls]

      if DEBUG:
      print "ppp",[(x.origin,x.getTwin().origin) for x in d.getEdges()]
      for ww in dgnls:
            print ww in [(x.origin,x.getTwin().origin) for x in d.getEdges()]
      dgnls = list(set(dgnls)-set([(x.origin,x.getTwin().origin) for x in
d.getEdges()]))
      return dgnls
```

## Screenshots:

I. N = 20

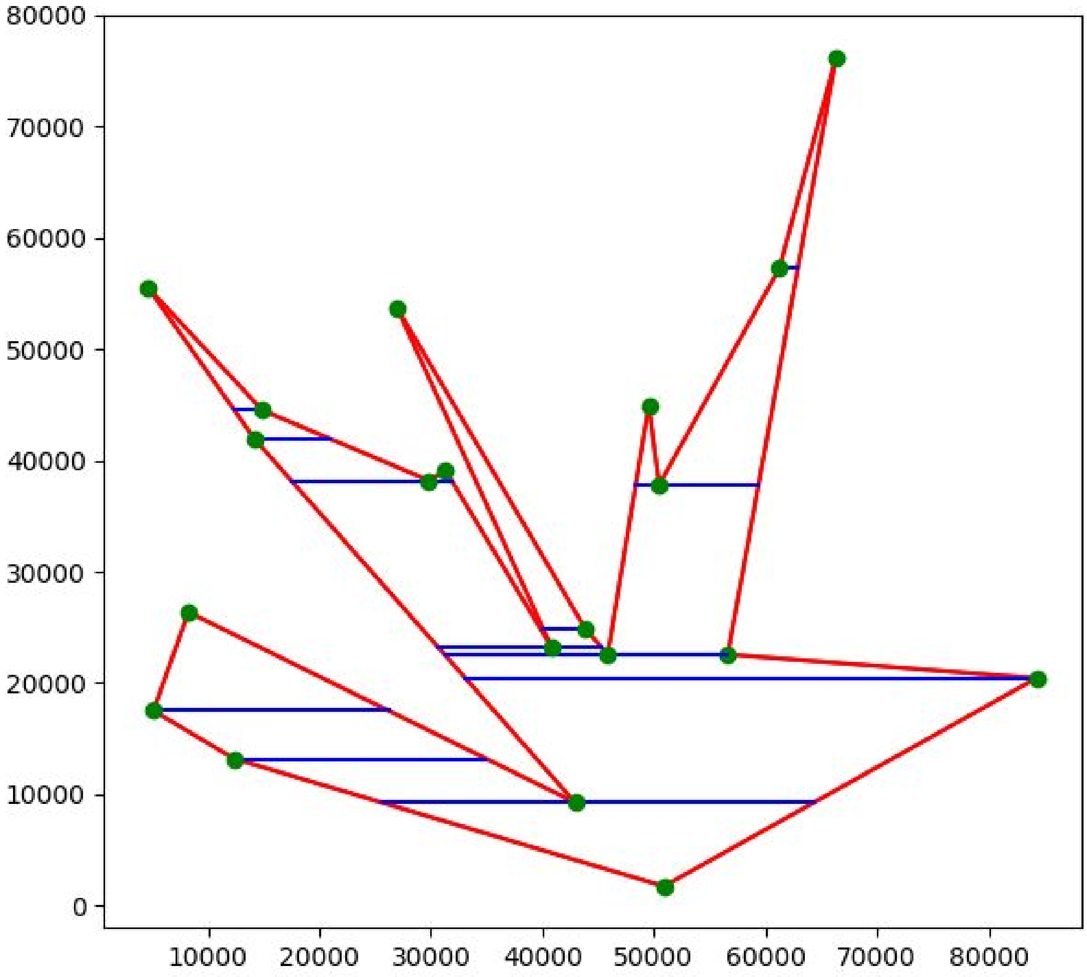


Fig: TrapEdges

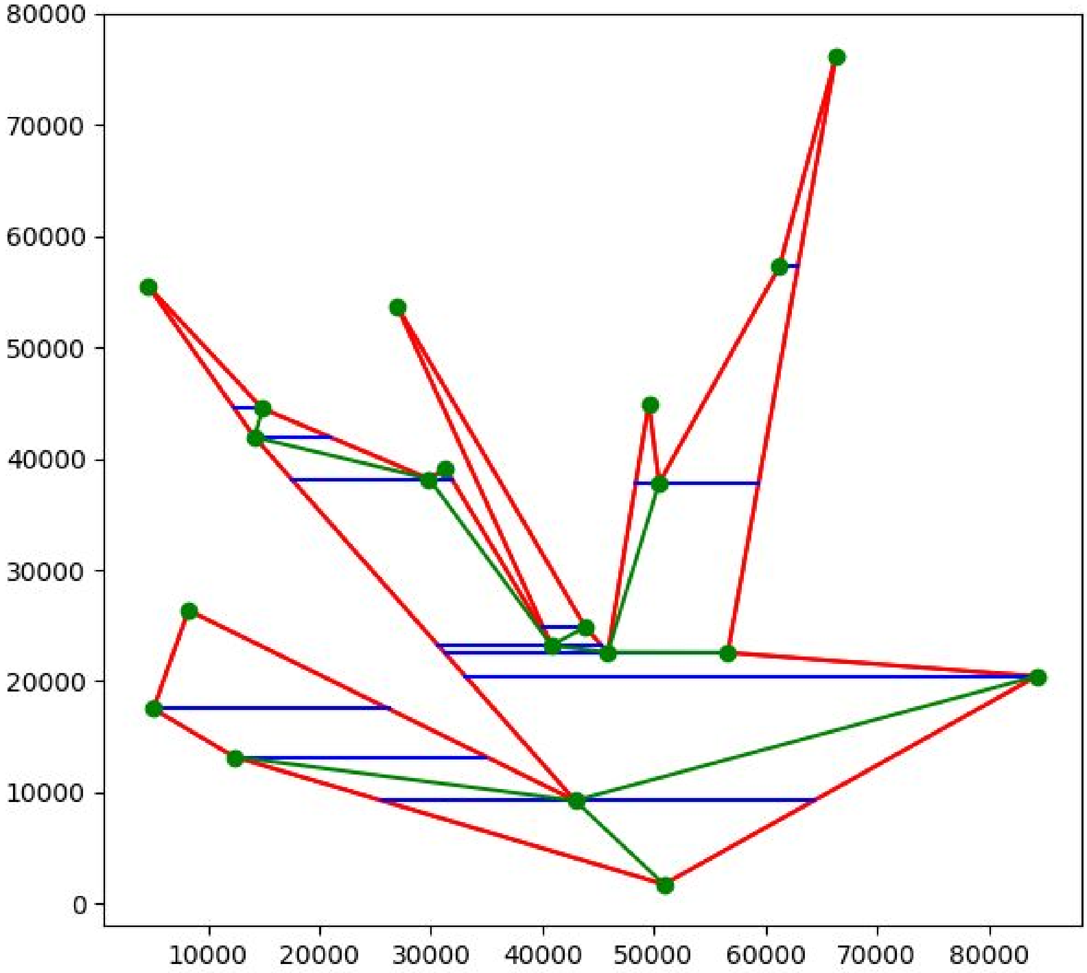


Fig: Trapezoid diagonals

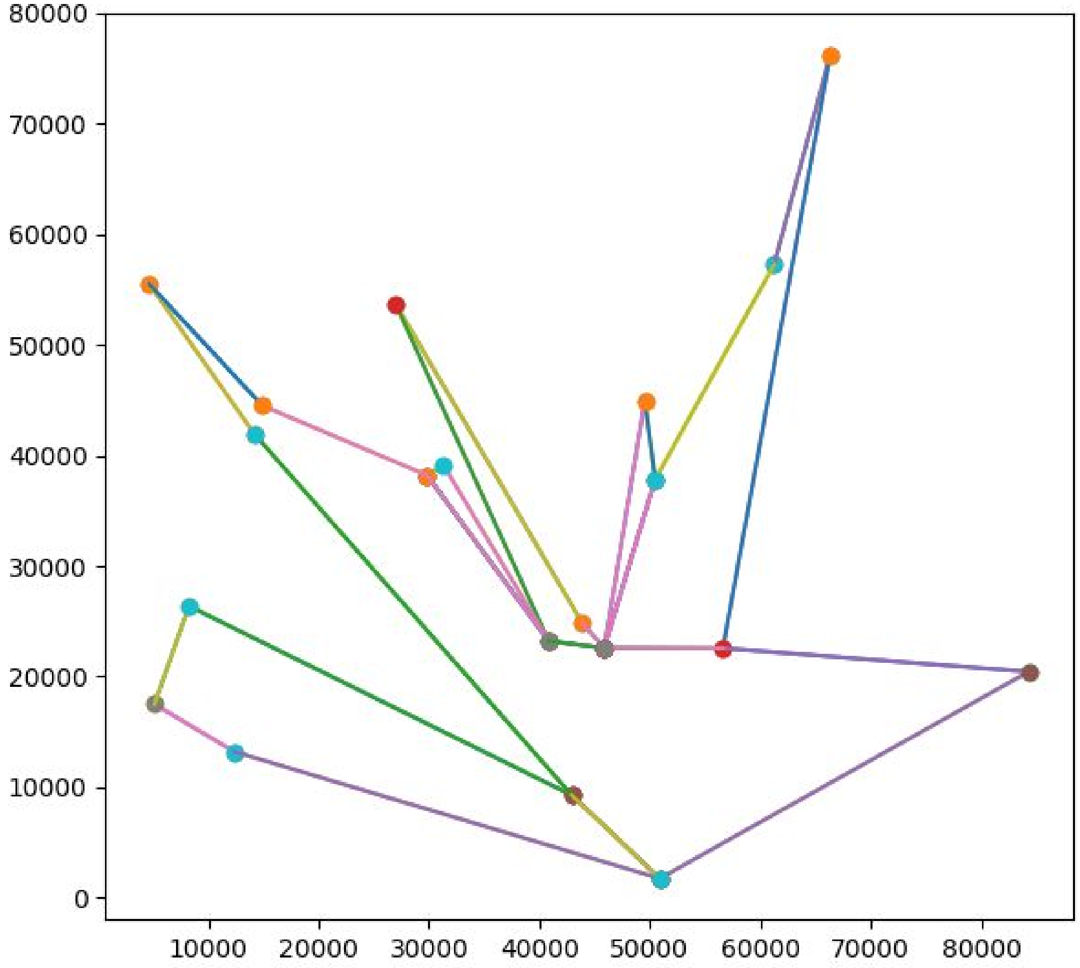


Fig: Monotone Partiotions

- For each monotone partition (polygon), perform triangulation using the line-sweep (plane-sweep) algorithm.
- Store the information in the required data structure (another DCEL)

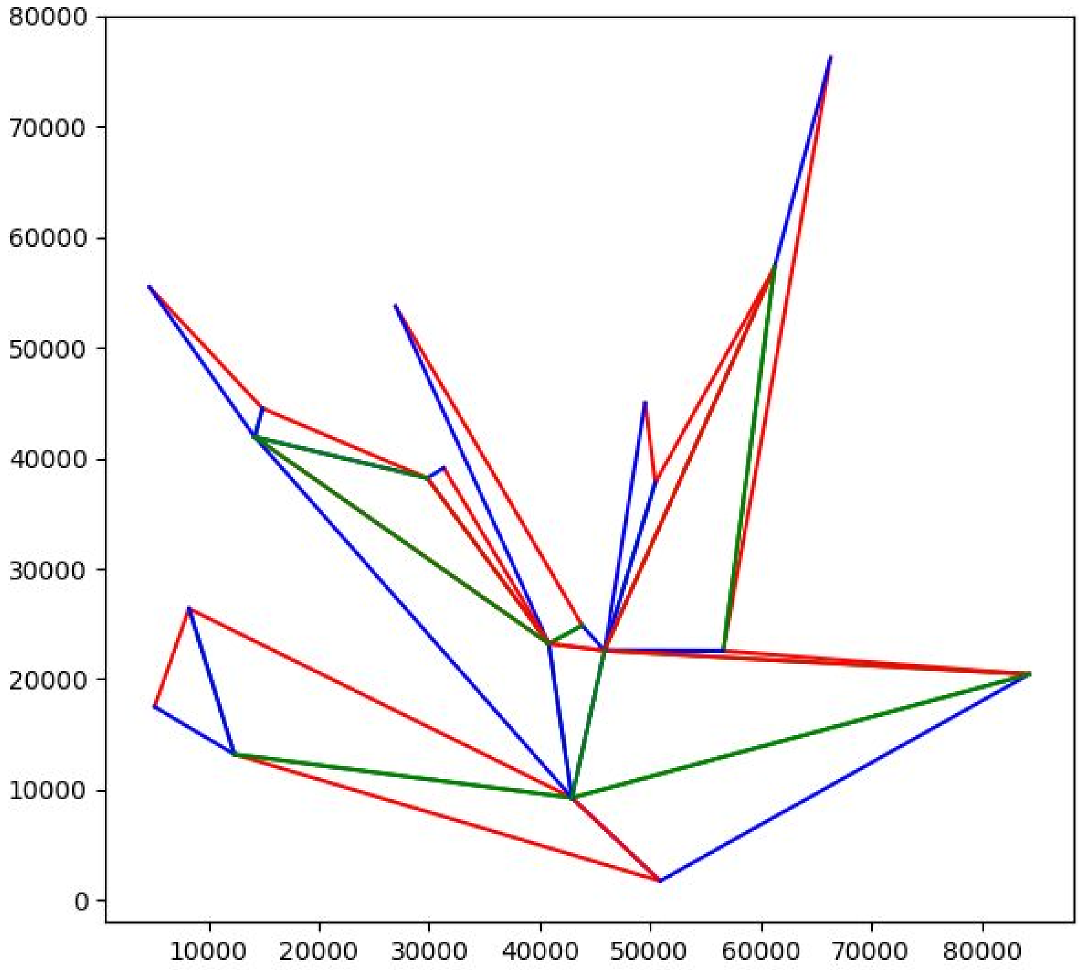
## Implementation

```
# triangulate Monotone Polygon // get list of diagonals

def Orientation(p,q,r):
        p=p.coords
        q=q.coords
        r=r.coords
        val = ( q[1] - p[1] )*( r[0] - q[0] ) - ( q[0] - p[0] )* ( r[1] - q[1] )
        return -val

def reflex(p,q,r,chain = 'l'):
        if(chain == 'r'):
        if Orientation(p,q,r)>=0:
                return True
        else:
                return False
        elif(chain == 'l'):
        if Orientation(p,q,r)>0:
                return False
        else:
                return True


def triangulateMonotonePolygon(d):
        pts = [x.origin for x in d.getFaces()[1].getOuterBoundary()]
        if DEBUG:
        print "Polygon Boundary:",[x.coords for x in pts]
        min_index = min(enumerate(pts), key=lambda x:x[1].coords[1])[0]
        max_index = max(enumerate(pts), key=lambda x:x[1].coords[1])[0]
        tmp1 = min(min_index,max_index)
        tmp2 = max(min_index,max_index)
        chain1 = pts[tmp1:(tmp2+1)]
        chain2 = pts[tmp2:]+pts[:(tmp1+1)]

        if(min(chain1, key=lambda x:x.coords[0]).coords[0] >min(chain2, key=lambda
x:x.coords[0]).coords[0]):    # ensuring chain1 is left chain
        if DEBUG:
                print "Monotone chains swapped"
        tmp = list(chain1)
        chain1 = chain2
        chain2 = tmp
        if DEBUG:
        print "Left Chain     : ",[x.coords for x in chain1]
        print "Right Chain    : ",[x.coords for x in chain2]
        pts = sorted(pts, key = lambda x:-x.coords[1])
        if DEBUG:
        print "\nSorted pts   : ",[x.coords for x in pts]
        print

        queue = []
        diagonals = []

        queue.append(pts[0])
        queue.append(pts[1])

        i = 2
        while i < (len(pts)-1):
        if DEBUG:
                print "\ni =",i,";",pts[i].coords
        #process(pts[i])
        tmp1 = queue[-1] in chain1
        tmp2 = pts[i] in chain1
        if (tmp1 and not tmp2) or (tmp2 and not tmp1):
                for qpt in queue[1:]:
                diagonals.append((pts[i], qpt))
                if DEBUG:
                        print "Case: a;  \nDiagonals:", [(x[0].coords,x[1].coords) for x in
diagonals]
                queue = [queue[-1],pts[i]]
                if DEBUG:
                print "Queue: ",[x.coords for x in queue]
        else:
                if DEBUG:
                print "||||||",queue[-2],queue[-1],pts[i],"chain =", ('l' if tmp1 else
'r'),"|||||"
                print reflex(queue[-2],queue[-1],pts[i],chain = ('l' if tmp1 else 'r') )
                print Orientation(queue[-2],queue[-1],pts[i] )
                if reflex(queue[-2],queue[-1],pts[i],chain = ('l' if tmp1 else 'r') ):
                queue.append(pts[i])
                if DEBUG:
                        print "Case: b;  \nDiagonals:",# reflex
                        print [(x[0].coords,x[1].coords) for x in diagonals]
                        print "Queue: ",[x.coords for x in queue]
                else:
                diagonals.append((pts[i], queue[-2]))
                if DEBUG:
                        print "Case: c;  \nDiagonals:", # convex
                        print [(x[0].coords,x[1].coords) for x in diagonals]
                        print "Queue: ",[x.coords for x in queue]
                queue.pop(-1)
                if len(queue) == 1:
                        queue.append(pts[i])
                else:
                        i-=1
        i+=1

        if len(queue)>2:
        for qpt in queue[1:-1]:
                diagonals.append((pts[i], qpt))
                if DEBUG:
                        print "Case: a;  \nDiagonals:", [(x[0].coords,x[1].coords) for x in
diagonals]
```

```
        if DEBUG:
        print "Queue: ",[x.coords for x in queue]
        return diagonals


triangulateMonotonePolygon(d)
listOfTriangles = insertDgnls(d,triangulateMonotonePolygon(d))
```

## Screenshots

n=20



- Now, assume that the simple polygon you constructed is the geometry of your Art-Gallery Problem. First, obtain the triangulated dual graph of that art-gallery. Then perform 3-coloring on the dual graph and determine the minimum number of vertex guards required to provide security of that Art-Gallery. Also, display the position of those vertex guards.

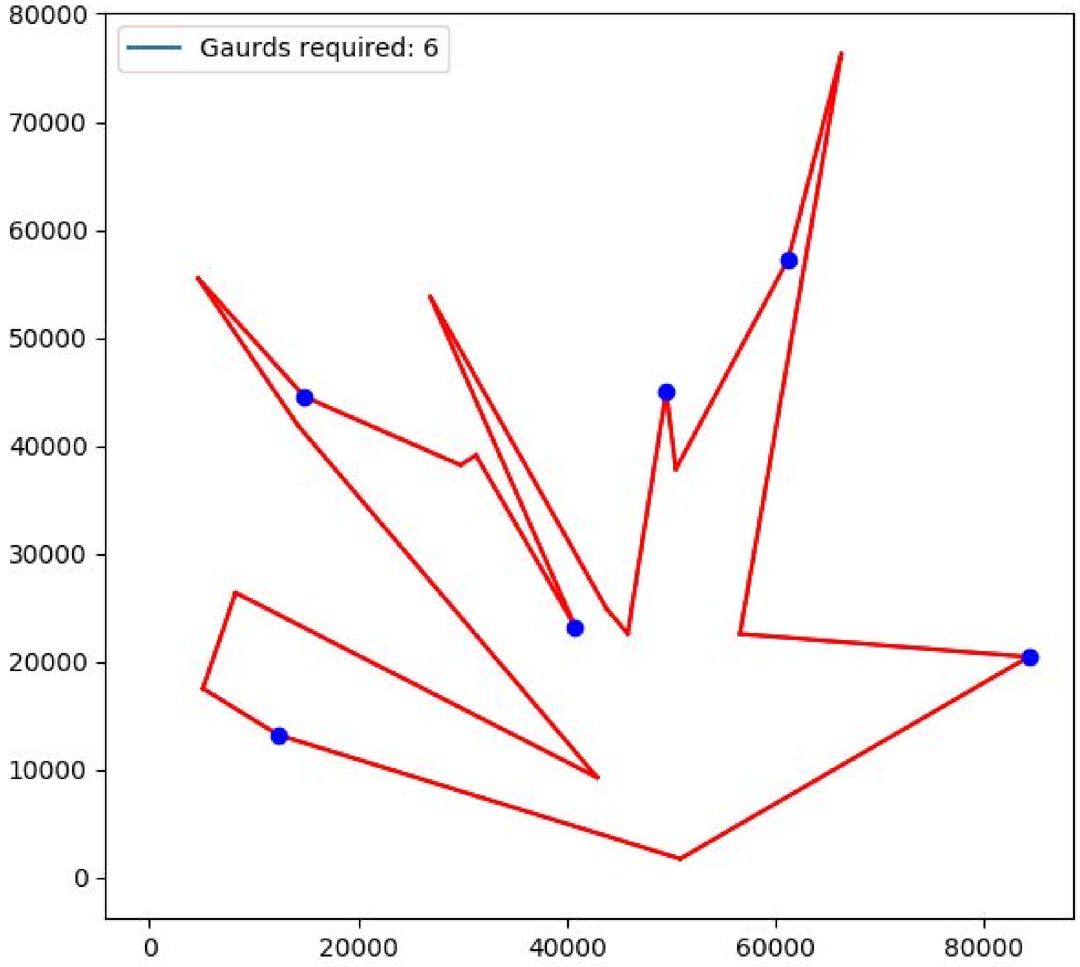
## Implementation

Colorizer class implements functions to obtain Dual Graph, to perform 3-coloring, to determine no. of vertex guards required as well as their positions. It uses triangulation generated in earlier steps.

```
class Colorizer(object):
      def __init__(self,d,listTriangle):
      #Initialize color to -1
      self.colors = {v.coords:-1 for v in d.getVertices()}

      #Creating Dual Graph
      self.vdual={i:listTriangle[i] for i in range(0,len(listTriangle))}
      self.edual={}
      for i in range(0,len(listTriangle)):
            j=i+1
            for j in range(0,len(listTriangle)):
            triangle_i = [x.coords for x in listTriangle[i]]
            triangle_j = [x.coords for x in listTriangle[j]]
            if len(list(set(triangle_i)&set(triangle_j))) > 1:
                  if i in self.edual and j not in self.edual[i] and i is not
j:
                        self.edual[i].append(j)
                  elif i not in self.edual and i is not j:
                        self.edual[i]=[j]
                  if j in self.edual and i not in self.edual[j] and i is not
j:
                        self.edual[j].append(i)
                  elif j not in self.edual and i is not j:
                        self.edual[j]=[i]
```

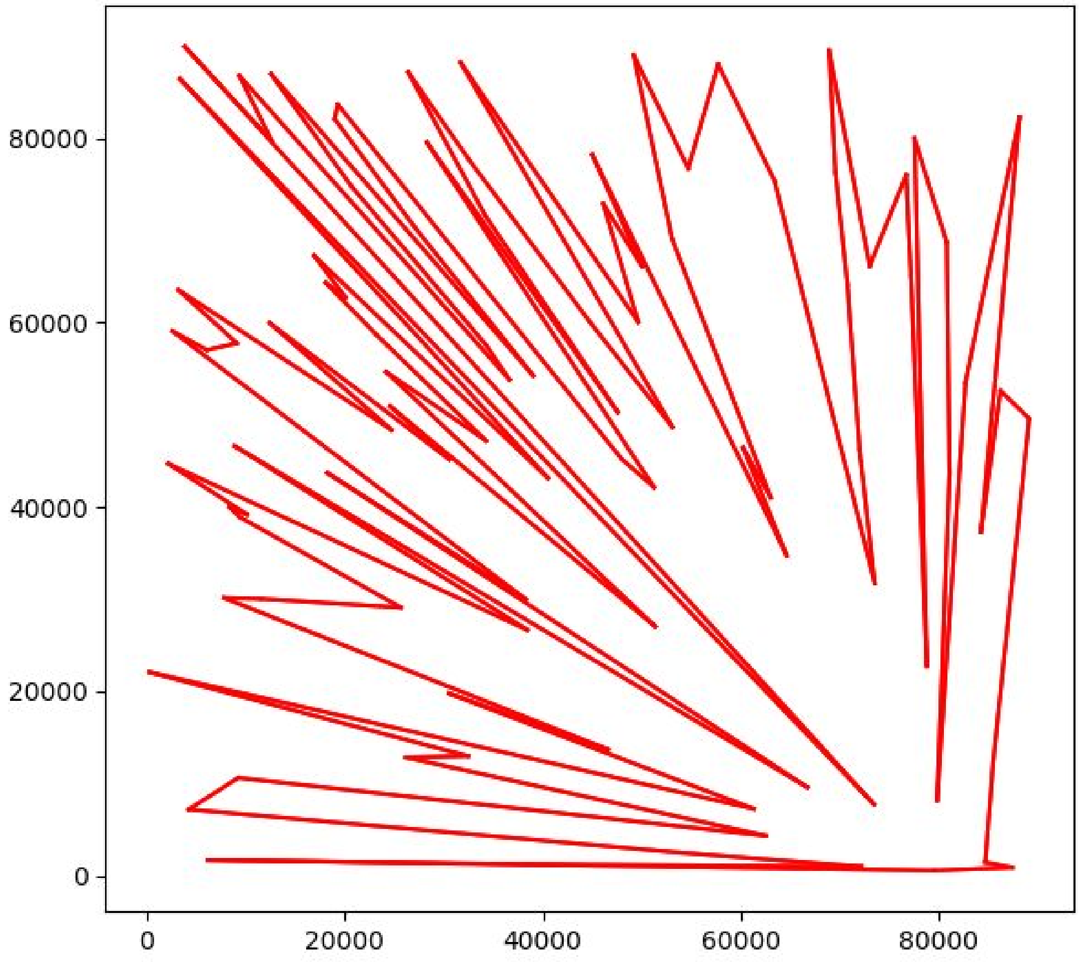
```
    def DFS(self,s):
    visited, stack = set(), [s]
    while stack:
        vertex = stack.pop()
        if vertex not in visited:
        colorsum =
self.colors[self.vdual[vertex][0].coords]+self.colors[self.vdual[vertex][1].co
ords]+self.colors[self.vdual[vertex][2].coords]
        if DEBUG:
            print "Changing Coloring of Triangle#:"+str(vertex)+"
from:
",self.colors[vdual[vertex][0].coords],self.colors[vdual[vertex][1].coords],se
lf.colors[vdual[vertex][2].coords]
        if colorsum<3:
            if self.colors[self.vdual[vertex][0].coords] is -1:
                self.colors[self.vdual[vertex][0].coords] =
3-self.colors[self.vdual[vertex][1].coords]-self.colors[self.vdual[vertex][2].
coords]
            elif self.colors[self.vdual[vertex][1].coords] is -1:
                self.colors[self.vdual[vertex][1].coords] =
3-self.colors[self.vdual[vertex][0].coords]-self.colors[self.vdual[vertex][2].
coords]
            elif self.colors[self.vdual[vertex][2].coords] is -1:
                self.colors[self.vdual[vertex][2].coords] =
3-self.colors[self.vdual[vertex][1].coords]-self.colors[self.vdual[vertex][0].
coords]
        if DEBUG:
            print "to:
",self.colors[self.vdual[vertex][0].coords],self.colors[self.vdual[vertex][1].
coords],self.colors[self.vdual[vertex][2].coords]
        visited.add(vertex)
        stack.extend(set(self.edual[vertex]) - visited)

    def colorize(self):
    #key = first triangle to be 3-colored
    key = 0
    if DEBUG:
        print("############################ INITIAL COLORING OF ONE
TRIANGLE ##################################")
        print ("Triangle #"+str(key)+" Vertex #0 colored to 0")
    self.colors[self.vdual[key][0].coords] = 0
    if DEBUG:
        print ("Triangle #"+str(key)+" Vertex #1 colored to 1")
    self.colors[self.vdual[key][1].coords] = 1
    if DEBUG:
        print ("Triangle #"+str(key)+" Vertex #2 colored to 2")
    self.colors[self.vdual[key][2].coords] = 2
    if DEBUG:
        print("############################ GOING TO COLOR REMAINING
TRIANGLES ###############################")
    self.DFS(key)
    output,col = self.findMinColor()
    return output,col
```

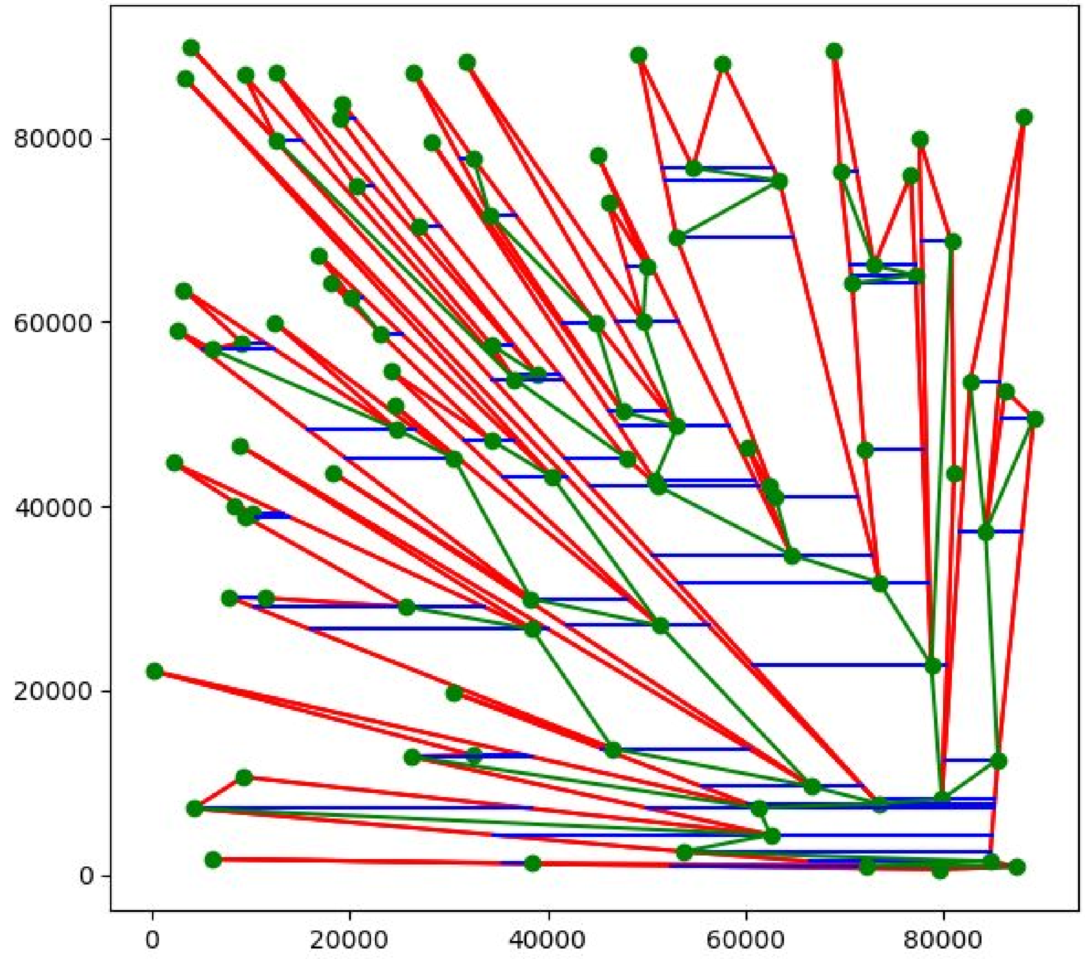
```
      def findMinColor(self):
      rcount,gcount,bcount=0,0,0
      r,g,b=[],[],[]
      out= set()
      for t in self.vdual.values():
            for it in t:
            if it.coords not in out:
                  if self.colors[it.coords] is 0:
                        rcount+=1
                        r.append(it)
                  elif self.colors[it.coords] is 1:
                        gcount+=1
                        g.append(it)
                  elif self.colors[it.coords] is 2:
                        bcount+=1
                        b.append(it)
                  out.add(it.coords)
      if rcount is gcount and rcount is bcount:
            return r,rcount
      if rcount<=gcount and rcount<=bcount:
            return r,rcount
      if gcount<=rcount and gcount<=bcount:
            return g,gcount
      if bcount<=rcount and bcount<=gcount:
            return b,bcount

colorizer = Colorizer(d,listOfTriangles)
colorizer.colorize()
```

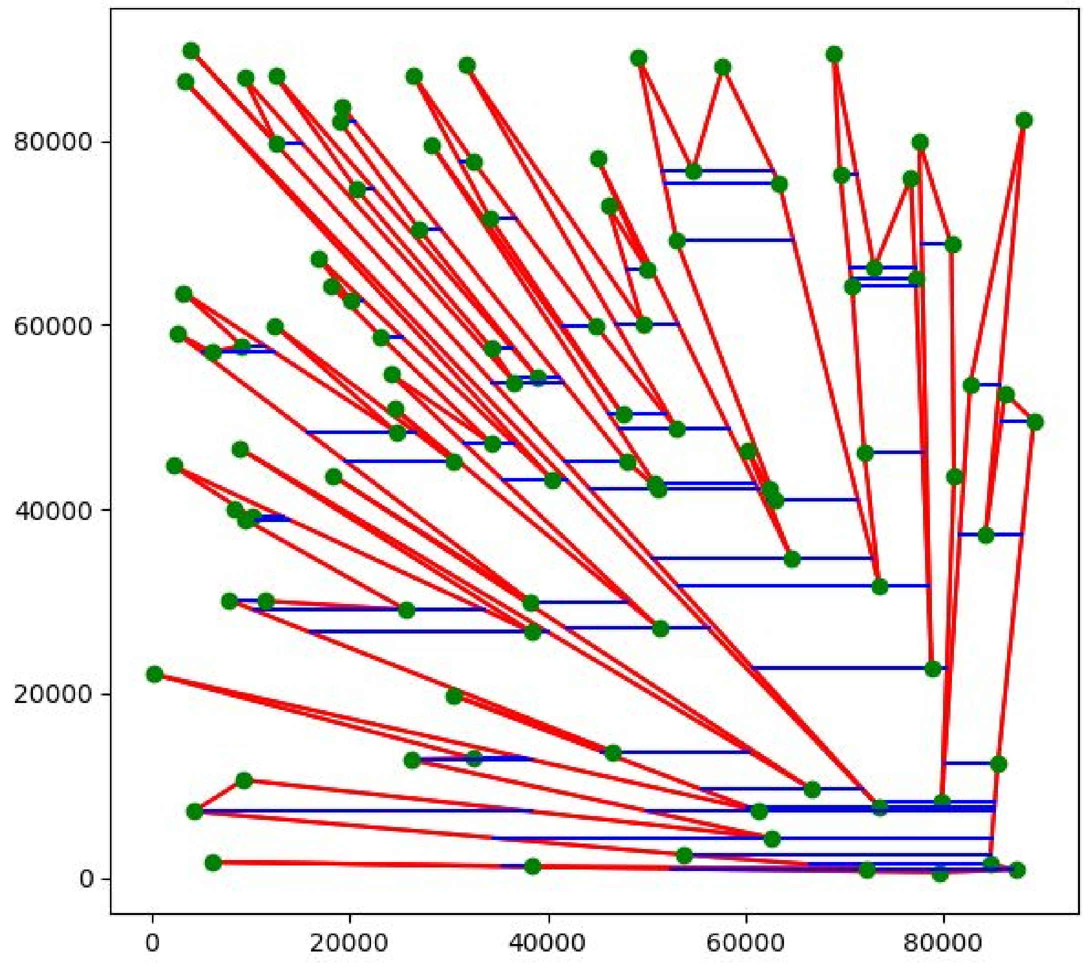

Gaurds required: 6
80000
70000
60000
50000
40000
30000
20000
10000
0
0
20000
40000
60000
80000

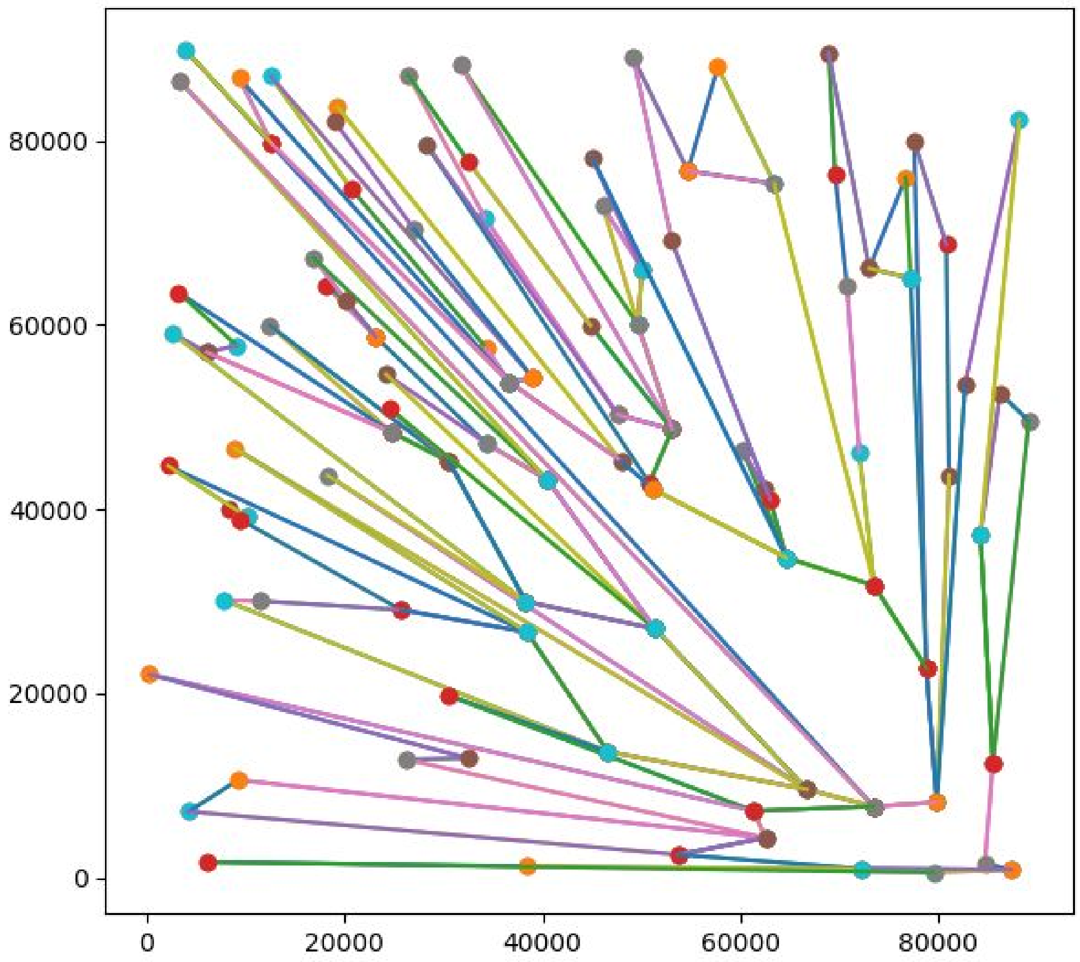
Screenshots

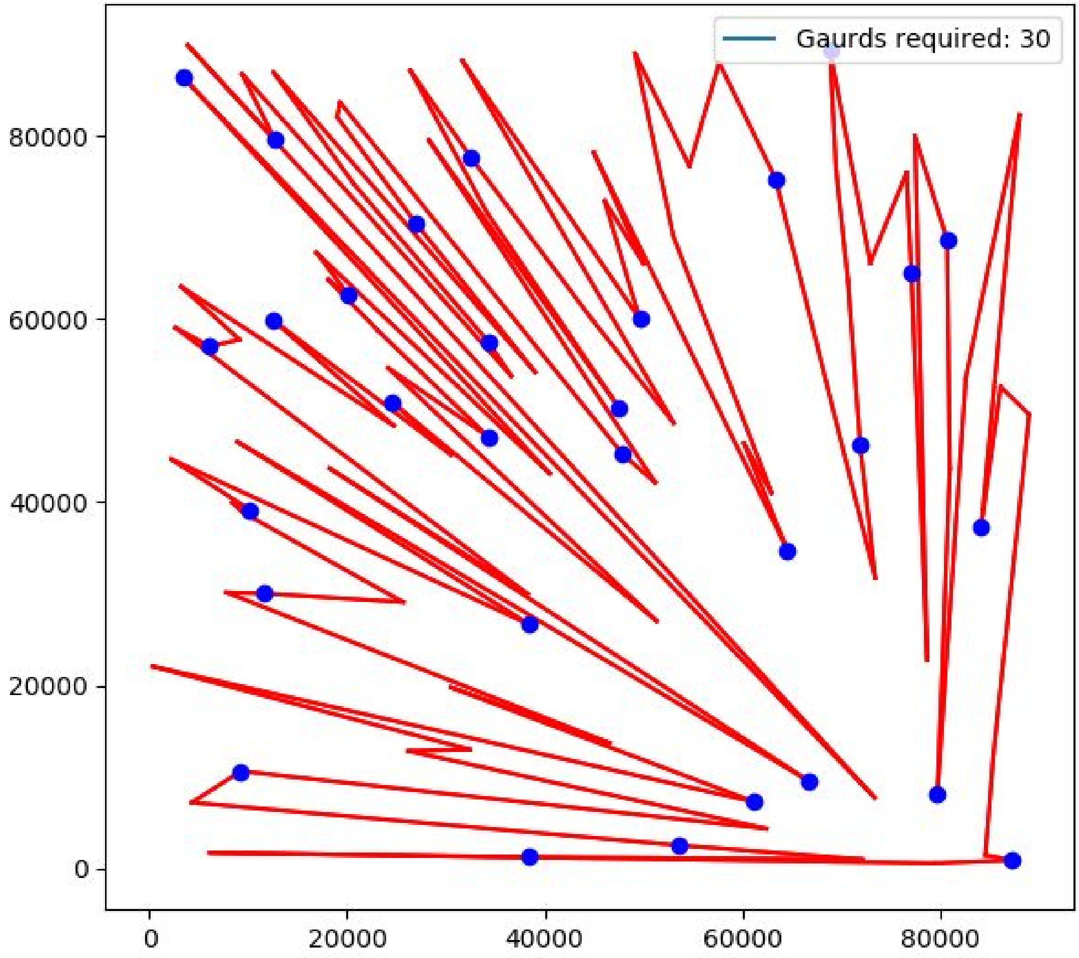
n=100

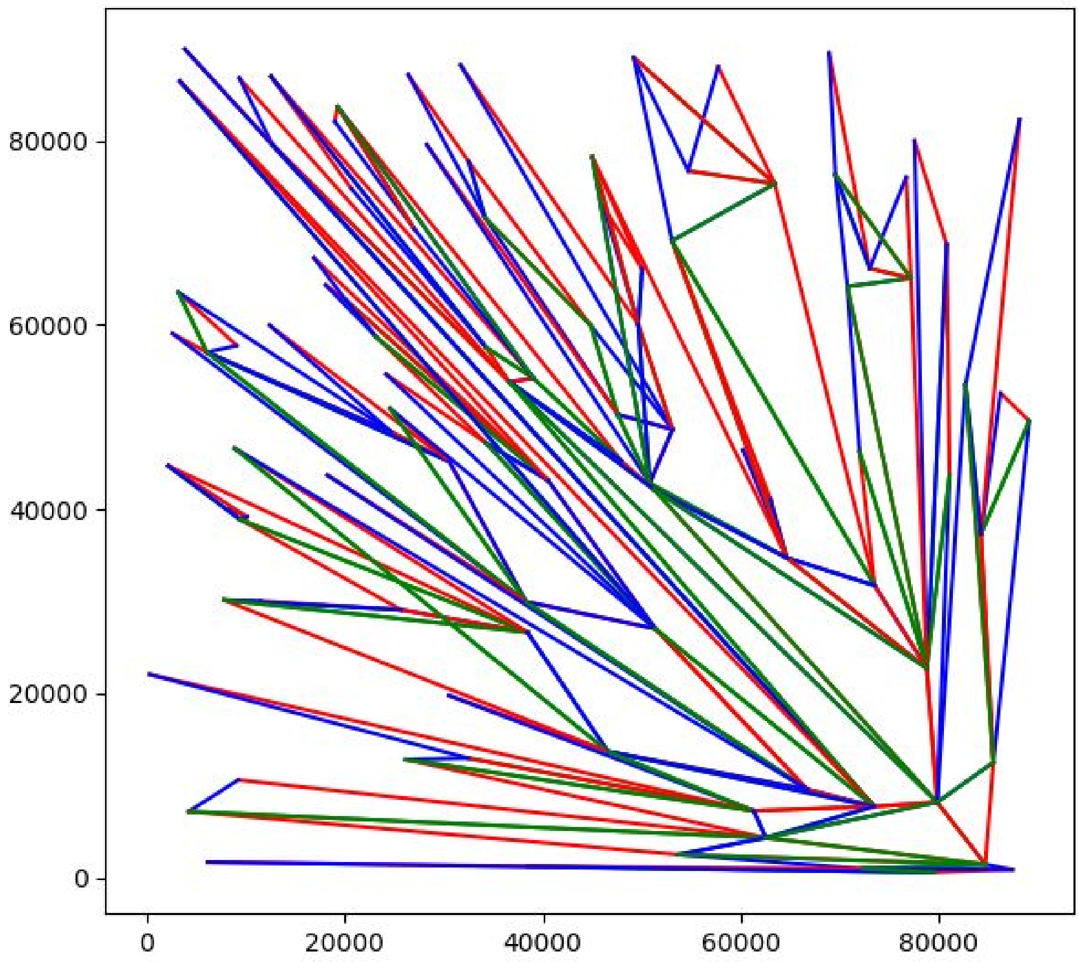



80000
60000
40000
20000
0
0
20000
40000
60000
80000


0
20000
40000
60000
80000
0
20000
40000
60000
80000


80000
60000
40000
20000
0
0
20000
40000
60000
80000


Gaurds required: 30
80000
60000
40000
20000
0
0
20000
40000
60000
80000


80000
60000
40000
20000
0
0
20000
40000
60000
80000