VIT®

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

Vellore-632014, Tamil Nadu, India

J COMPONENT PROJECT REPORT - Data Structures and Algorithm

REVIEW 3

L53-54

PROF. SHALINI L

A Joint Effort and an Unified attempt by:
1.NAKUL SINGH 18BIS0128
2.MRINMAY 18BIS0147

Abstract :

Problem statement(Travelling Salesman Problem - TSP) –
Given a set of cities and distance between every pair of cities, the problem is to find the shortest possible route that visits every city exactly once and returns to the starting point. Compare the time taken to find the shortest route possible by Ant Colony Optimization and Brute Force Technique.

Ant Colony Optimization (ACO) Technique: (Review 1)

Introduction-

In the natural world, ants of some species (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but instead to follow the trail, returning and reinforcing it if they eventually find food.

Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones. Pheromone evaporation also has the advantage of avoiding the convergence to a locally optimal solution. If there were no evaporation at all, the paths chosen by the first ants would tend to be excessively attractive to the following ones. In that case, the exploration of the solution space would be constrained. The influence of pheromone evaporation in real ant systems is unclear, but it is very important in artificial systems.

The overall result is that when one ant finds a good (i.e., short) path from the colony to a food source, other ants are more likely to follow that path, and positive feedback eventually leads to many ants following a single path. The idea of the ant colony algorithm is to mimic this behaviour with "simulated ants" walking around the graph representing the problem to solve.

Given an n-city TSP with distances d_{ij}, the artificial ants are distributed to these n cities randomly. Each ant will choose the next to visit according to the pheromone trail remained on the paths just as mentioned in the above example. However, there are two main differences between artificial ants and real ants: (1) the artificial ants have “memory”; they can remember the cities they have visited and therefore they would not select those cities again. (2) The artificial ants are not completely “blind”; they know the distances between two cities and prefer to choose the nearby cities from their positions. Therefore, the probability that city j is selected by ant k to be visited after city i could be written as follows:

$$p_{ij}^{k} = \begin{cases} \frac{[\tau_{ij}]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum_{s \in allowed_k} [\tau_{is}]^{\alpha} \cdot [\eta_{is}]^{\beta}} & j \in allowed_k \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where τ_{ij} is the intensity of pheromone trail between cities i and j, α the parameter to regulate the influence of τ_{ij}, η_{ij} the visibility of city j from city i, which is always set as $1/d_{ij}$ (d_{ij} is the distance between city i and j), β the parameter to regulate the influence of η_{ij} and $allowed_k$ the set of cities that have not been visited yet, respectively.

At the beginning, l ants are placed to the n cities randomly. Then each ant decides the next city to be visited according to the probability p_{ij}^{k} given by Eq. (1). After $n$iterations of this process, every ant completes a tour. Obviously, the ants with shorter tours should leave more pheromone than those with longer tours. Therefore, the trail levels are updated as on a tour each ant leaves pheromone quantity given by Q/L_k, where Q is a constant and L_k the length of its tour, respectively. On the other hand, the pheromone will evaporate as the time goes by. Then the updating rule of τ_{ij} could be written as follows:

$$\tau_{ij}(t+1) = \rho \cdot \tau_{ij}(t) + \Delta\tau_{ij} \tag{2}$$

$$\Delta\tau_{ij} = \textstyle\sum_{k=1}^{l} \Delta\tau_{ij}^{k} \tag{3}$$

$$\Delta\tau_{ij}^{k} = \begin{cases} Q/L_k & \text{if ant } k \text{ travels on edge } (i,j) \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where t is the iteration counter, $\rho \in [0, 1]$ the parameter to regulate the reduction of τ_{ij}, $\Delta\tau_{ij}$ the total increase of trail level on edge (i, j) and $\Delta\tau_{ij}{}^{k}$ the increase of trail level on edge (i, j) caused by ant k, respectively.
After the pheromone trail updating process, the next iteration $t + 1$ will start.

Othe real-life Applications –

- Vehicle Routing Problems.
- Real world games like ‘Pokemon Go’ and other Augmented Reality applications.
- Image Edge Detection – (https://www.researchgate.net/publication/228848216_Image_edge_detection_using_ant_colony_optimization)

Implementation of TSP using Ant Colony Optimization(ACO) :-
CODE- Python 3 and above supported:-

Main.py –

```
import math
import sys
import time
start = time.time()
from aco import ACO, Graph
from plot import plot


def distance(citY1: dict, city2: dict):
    return math.sqrt((citY1['x'] - city2['x']) ** 2 + (citY1['y'] - city2['y']) ** 2)


def   main():
    cities  =  []
    points = []
    with open('./data/chn144.txt') as f:
        for line in f.readlines():
            city = line.split(' ')
            cities.append(dict(index=int(city[0]), x=int(city[1]), y=int(city[2])))
            points.append((int(city[1]), int(city[2])))
    cost_matrix = []
    rank = len(cities)
    for i in range(rank):
        row = []
        for j in range(rank):
            row.append(distance(cities[i], cities[j]))
        cost_matrix.append(row)
    aco = ACO(10, 100, 1.0, 10.0, 0.5, 10, 2)
    graph = Graph(cost_matrix, rank)
    path, cost = aco.solve(graph)
    print('cost: {}, path: {}'.format(cost, path))
    plot(points, path)

if__name__== '_main_':
    main()
    end = time.time()
    print("time taken :",end-start)
    sys.exit(0)
```

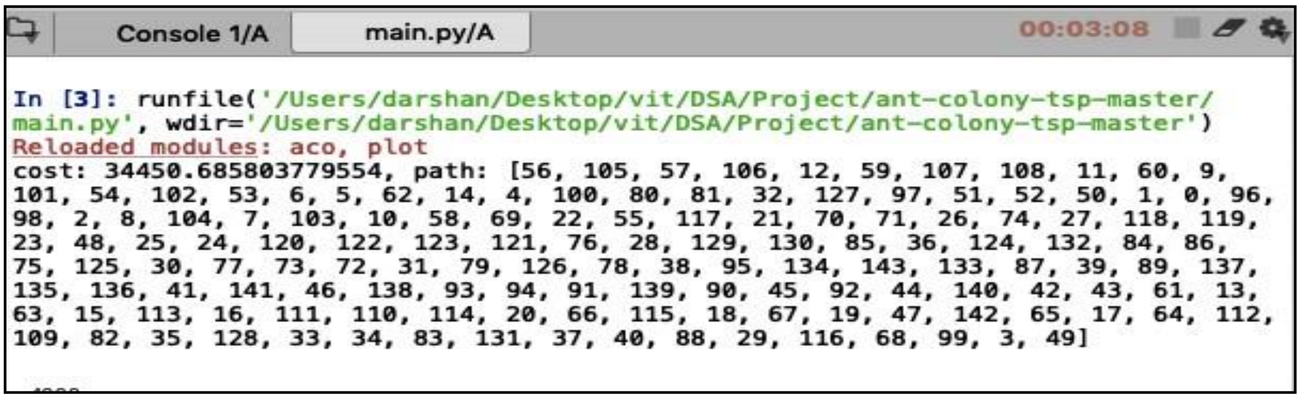
ACO.py –

```
import random
class Graph(object):
    def_init_(self, cost_matrix: list, rank: int):
        """
        :param cost_matrix:
        :param rank: rank of the cost matrix
        """
        self.matrix = cost_matrix
        self.rank = rank
        # noinspection PyUnusedLocal
        self.pheromone = [[1 / (rank * rank) for j in range(rank)] for i in range(rank)]

class ACO(object):
    def_init_(self, ant_count: int, generations: int, alpha: float, beta: float, rho: float, q: int,
              strategy: int):
        """
        :param ant_count:
        :param generations:
        :param alpha: relative importance of pheromone
        :param beta: relative importance of heuristic information
        :param rho: pheromone residual coefficient
        :param q: pheromone intensity
        :param strategy: pheromone update strategy. 0 - ant-cycle, 1 - ant-quality, 2 - ant-density
        """
        self.Q = q
        self.rho = rho
        self.beta = beta
        self.alpha = alpha
        self.ant_count = ant_count
        self.generations = generations
        self.update_strategy = strategy

    def _update_pheromone(self, graph: Graph, ants: list):
        for i, row in enumerate(graph.pheromone):
            for j, col in enumerate(row):
                graph.pheromone[i][j] *= self.rho
                for ant in ants:
                    graph.pheromone[i][j] += ant.pheromone_delta[i][j]

    # noinspection PyProtectedMember
    def solve(self, graph: Graph):
        """
        :param graph:
        """
        best_cost = float('inf')
        best_solution = []
        for gen in range(self.generations):
            # noinspection PyUnusedLocal
            ants = [_Ant(self, graph) for i in range(self.ant_count)]
            for ant in ants:
                for i in range(graph.rank - 1):
                    ant._select_next()
                ant.total_cost += graph.matrix[ant.tabu[-1]][ant.tabu[0]]
                if ant.total_cost < best_cost:
                    best_cost = ant.total_cost
                    best_solution = [] + ant.tabu
                # update pheromone
                ant._update_pheromone_delta()
            self._update_pheromone(graph, ants)
            # print('generation #{}, best cost: {}, path: {}'.format(gen, best_cost, best_solution))
        return best_solution, best_cost

class _Ant(object):
    def_init_(self, aco: ACO, graph: Graph):
        self.colony = aco
        self.graph = graph
        self.total_cost = 0.0
        self.tabu = [] # tabu list
        self.pheromone_delta = [] # the local increase of pheromone
        self.allowed = [i for i in range(graph.rank)]  # nodes which are allowed for the next selection
        self.eta = [[0 if i == j else 1 / graph.matrix[i][j] for j in range(graph.rank)] for i in
                    range(graph.rank)] # heuristic information
        start = random.randint(0, graph.rank - 1)  # start from any node
        self.tabu.append(start)
        self.current = start
        self.allowed.remove(start)

    def _select_next(self):
        denominator = 0
        for i in self.allowed:
            denominator += self.graph.pheromone[self.current][i] ** self.colony.alpha * self.eta[self.current][
                                                                                i] ** self.colony.beta
        # noinspection PyUnusedLocal
        probabilities = [0 for i in range(self.graph.rank)] # probabilities for moving to a node in the next step
        for i in range(self.graph.rank):
            try:
                self.allowed.index(i) # test if allowed list contains i
                probabilities[i] = self.graph.pheromone[self.current][i] ** self.colony.alpha * \
                    self.eta[self.current][i] ** self.colony.beta / denominator
            except ValueError:
                pass # do nothing
        # select next node by probability roulette
        selected = 0
        rand = random.random()
        for i, probability in enumerate(probabilities):
            rand -= probability
            if rand <= 0:
                selected = i
                break
        self.allowed.remove(selected)
        self.tabu.append(selected)
        self.total_cost += self.graph.matrix[self.current][selected]
        self.current = selected

    # noinspection PyUnusedLocal
    def _update_pheromone_delta(self):
        self.pheromone_delta = [[0 for j in range(self.graph.rank)] for i in range(self.graph.rank)]
        for _ in range(1, len(self.tabu)):
            i = self.tabu[_ - 1]
            j = self.tabu[_]
            if self.colony.update_strategy == 1:  # ant-quality system
                self.pheromone_delta[i][j] = self.colony.Q
            elif self.colony.update_strategy == 2: # ant-density system
                # noinspection PyTypeChecker
                self.pheromone_delta[i][j] = self.colony.Q / self.graph.matrix[i][j]
            else: # ant-cycle system
                self.pheromone_delta[i][j] = self.colony.Q / self.total_cost
```

Plot.py –

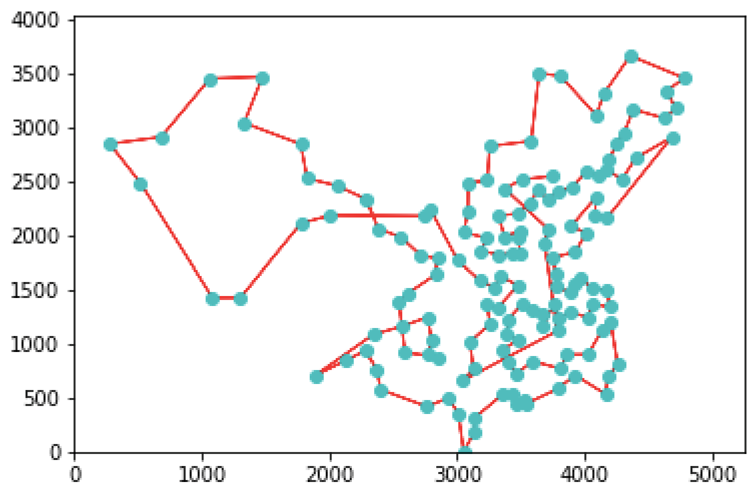
```
import operator
import matplotlib.pyplot as plt

def plot(points, path: list):
    x = []
    y = []
    for point in points:
        x.append(point[0])
        y.append(point[1])
    # noinspection PyUnusedLocal
    y = list(map(operator.sub, [max(y) for i in range(len(points))], y))
    plt.plot(x, y, 'co')

    for _ in range(1, len(path)):
        i = path[_ - 1]
        j = path[_]
        # noinspection PyUnresolvedReferences
        plt.arrow(x[i], y[i], x[j] - x[i], y[j] - y[i], color='r', length_includes_head=True)

    # noinspection PyTypeChecker
    plt.xlim(0, max(x) * 1.1)
    # noinspection PyTypeChecker
    plt.ylim(0, max(y) * 1.1)
    plt.show()
```

<u>Output -</u>



```
In [3]: runfile('/Users/darshan/Desktop/vit/DSA/Project/ant-colony-tsp-master/
main.py', wdir='/Users/darshan/Desktop/vit/DSA/Project/ant-colony-tsp-master')
Reloaded modules: aco, plot
cost: 34450.685803779554, path: [56, 105, 57, 106, 12, 59, 107, 108, 11, 60, 9,
101, 54, 102, 53, 6, 5, 62, 14, 4, 100, 80, 81, 32, 127, 97, 51, 52, 50, 1, 0, 96,
98, 2, 8, 104, 7, 103, 10, 58, 69, 22, 55, 117, 21, 70, 71, 26, 74, 27, 118, 119,
23, 48, 25, 24, 120, 122, 123, 121, 76, 28, 129, 130, 85, 36, 124, 132, 84, 86,
75, 125, 30, 77, 73, 72, 31, 79, 126, 78, 38, 95, 134, 143, 133, 87, 39, 89, 137,
135, 136, 41, 141, 46, 138, 93, 94, 91, 139, 90, 45, 92, 44, 140, 42, 43, 61, 13,
63, 15, 113, 16, 111, 110, 114, 20, 66, 115, 18, 67, 19, 47, 142, 65, 17, 64, 112,
109, 82, 35, 128, 33, 34, 83, 131, 37, 40, 88, 29, 116, 68, 99, 3, 49]
```

Graph depicting the route:



```
time taken : 49.74392604827881
```

Brute Force Technique: (Review 3)

Introduction-

Brute-force search or exhaustive search, also known as generate and test, is a very general problem-solving technique and algorithmic paradigm that consists of systematically enumerating all possible candidates for the solution and checking whether each candidate satisfies the problem's statement.

Implementation of TSP using Brute Force Technique – CODE- Python 3 and above supported:-

Main.py

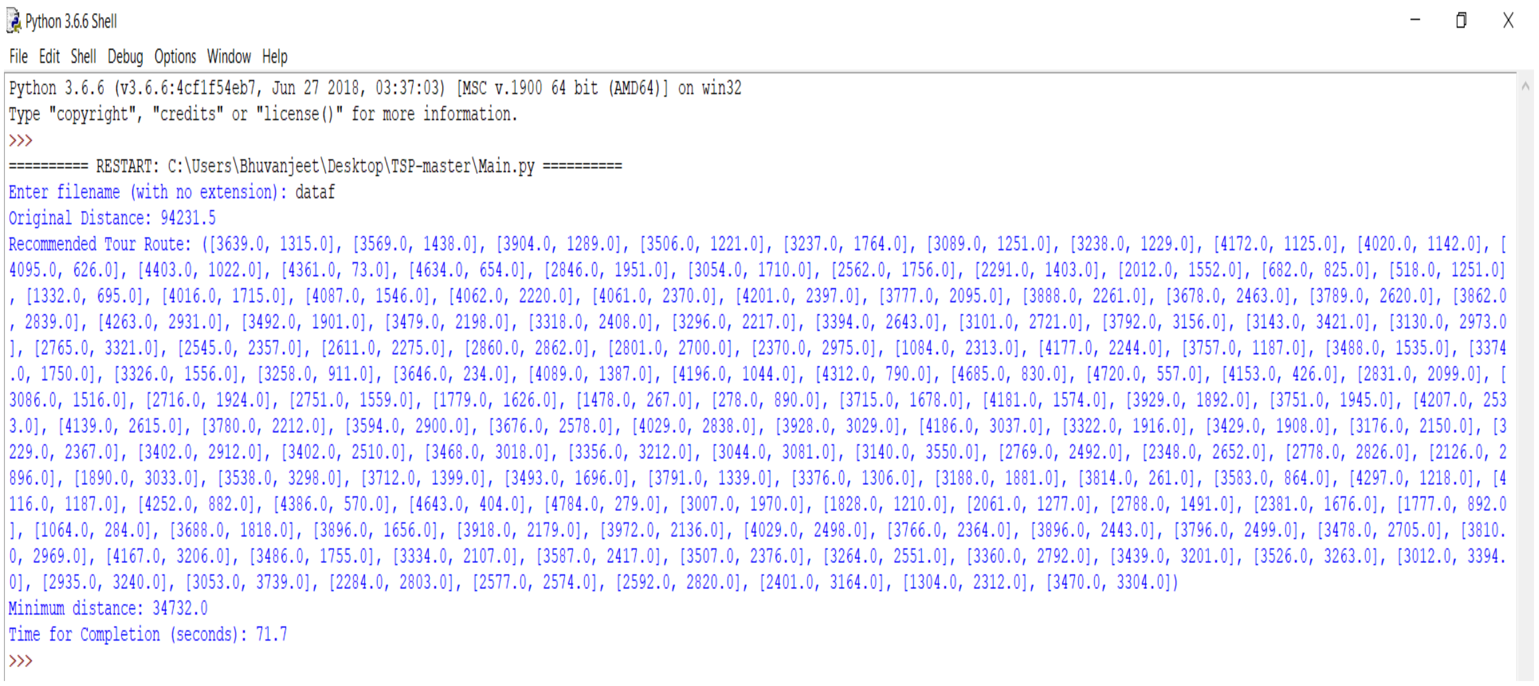
```
from timeit import Timer
from graph_tsp import graph_tsp
def runCode():
    var = str(input("Enter filename (with no extension): "))
    T = graph_tsp(var)

t1 = Timer("""runCode()""", """from __main__import runCode""")
print("Time for Completion (seconds): " '{0:.1f}'.format(t1.timeit(1)))
```

graph_tsp.py

```
from itertools import permutations
import csv
import logging
from colorama import Fore, Back, Style
import matplotlib.pyplot as plt

class graph_tsp():

    def_init_(self, filename):

        try:
            self.logger = self.setupLogger()
            self.filename = filename

            # Open CSV file and read each row into a list of lists
            with open('data/' + self.filename + '.csv', newline='') as file:
                reader = csv.reader(file)
                points_original = list(map(list, reader))

            # Remove header column
            del points_original[0]

            # Remove city index from the points
            cities = []
            for point in points_original:
                cities.append(point.pop(0))

            # Convert string values to float
            points = []
            for item in points_original:
                point = []
                for values in item:
                    point.append(float(values))
                points.append(point)

            # Show Plot for original data provided
            title = 'The TSP Original Data Route'
            self.plotIt(points, title)

            self.logger.info('CSV file data/' + self.filename + '.csv was read...')

            # Print distance
            print("""Original Distance: {} \nRecommended Tour Route: {} \nMinimum distance: {}""".format(
                '{0:.1f}'.format(self.total_distance(points)),
                tuple(points),
                '{0:.1f}'.format(self.total_distance(self.calculate_TSP(points)))))

        except Exception as e:
            self.logger.error(Fore.RED + 'Error reading CSV data/' + self.filename + '.csv file... %s' % str(e) +
Style.RESET_ALL)

    def setupLogger(self):
        logfile = 'logs/app_log.txt'
        # Format log to add time, level and message
        logging.basicConfig(level=logging.WARNING)
        logFormatter = logging.Formatter('%(asctime)s - %(levelname)s --: %(message)s')
        logger = logging.getLogger(_name_)
        # Add handler to send logs to log file
        handler = logging.FileHandler(logfile)
        handler.setFormatter(logFormatter)
        handler.setLevel(logging.INFO)
        logger.addHandler(handler)
        logger.info('Logs written in %s' % logfile)
        return logger

    def distance(self, point_one,
        point_two): complete = False
        try:
            distance = ( (point_one[0] - point_two[0]) ** 2.0 + (point_one[1] - point_two[1]) ** 2.0) ** 0.5
            complete = True
            return distance
        except Exception as e:
            self.logger.error(Fore.RED + 'Error calculating distance between points... %s' % str(e) +
Style.RESET_ALL)
        finally:
            if complete:
                self.logger.info('Distance between all points has been calculated...')

    def total_distance(self, points):
        # Determine if the function has been completed
        complete = False
        try:
            total_distance = sum([self.distance(p, points[value + 1]) for value, p in enumerate(points[:-1])])
            complete = True
            return total_distance
        except Exception as e:
            self.logger.error(Fore.RED + 'Error calculating total distance between points... %s' % str(e) +
Style.RESET_ALL)
        finally:
            if complete:
                self.logger.info('Total distance between all points has been calculated...')

    def calculate_TSP(self, points):
        # Determine if the function has been completed
        complete = False
        # Starting position
        start_position = points[0]
        # Places to visit
        visit_list = points
        # Set tour to starting position
        tour = [start_position]
        # Remove the starting position
        visit_list.remove(start_position)
        try:
            # Loop through places to visit to find min distance
            while visit_list:
                key_value = lambda y: self.distance(tour[-1], y)
                # Find nearest city
                nearest_city = min(visit_list, key = key_value)
                # Append nearest city to the tour and remove it from the visit list
                tour.append(nearest_city)
                visit_list.remove(nearest_city)
            complete = True

            # Show Plot for the evaluated min tour route order
            title = 'The TSP Calculated Minimum Route'
            self.plotIt(tour, title)

            return tour
        except Exception as e:
            self.logger.error(Fore.RED + 'Error calculating minimum distance between points and finding total
path... %s' % str(e) + Style.RESET_ALL)
        finally:
            if complete:
                self.logger.info('Minimum distance between all points and path have been calculated...')

    def plotIt(self, tour_points, title):
```

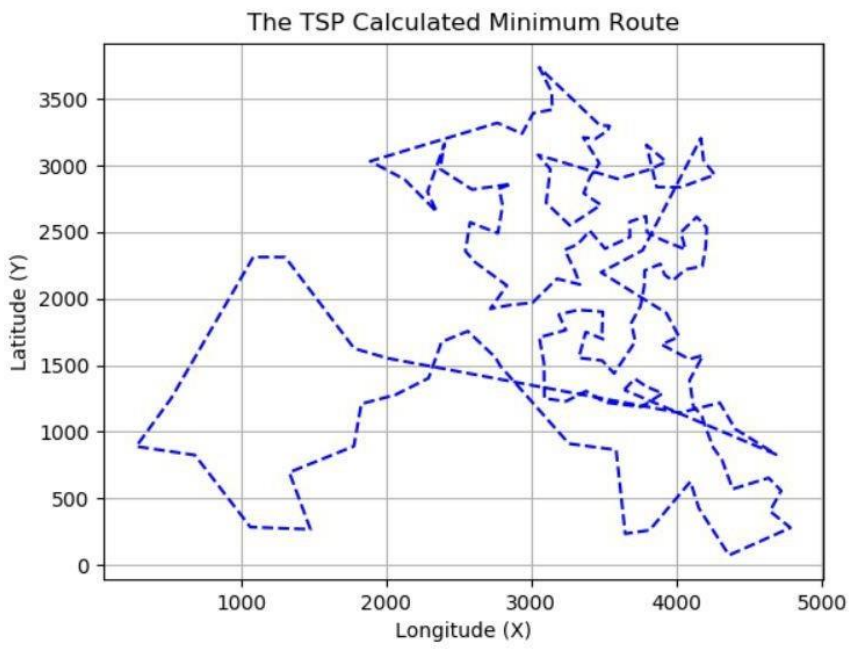
```
    try:
        # Grab X and Y values of points
        x = []
        y = []
        for values in tour_points:
            x.append(values[0])
            y.append(values[1])

        # Append the first item to the end to complete the loop
        x.append(x[0])
        y.append(y[0])

        # Setup plot
        plt.plot(x, y, 'b--')
        plt.xlabel('Longitude (X)')
        plt.ylabel('Latitude (Y)')
        plt.title(title)
        plt.grid(True)

        # Plot TSP route
        plt.show()

        self.logger.info('Plot created of route... ')
    except Exception as e:
        self.logger.error(Fore.RED + 'Error plotting route. Check data provided and/or graph settings... %s' %
str(e) + Style.RESET_ALL)
```

Output-



```
Python 3.6.6 (v3.6.6:4cf1f54eb7, Jun 27 2018, 03:37:03) [MSC v.1900 64 bit (AMD64)] on win32
Type "copyright", "credits" or "license()" for more information.
>>>
========== RESTART: C:\Users\Bhuvanjeet\Desktop\TSP-master\Main.py ==========
Enter filename (with no extension): dataf
Original Distance: 94231.5
Recommended Tour Route: ([3639.0, 1315.0], [3569.0, 1438.0], [3904.0, 1289.0], [3506.0, 1221.0], [3237.0, 1764.0], [3089.0, 1251.0], [3238.0, 1229.0], [4172.0, 1125.0], [4020.0, 1142.0], [
4095.0, 626.0], [4403.0, 1022.0], [4361.0, 73.0], [4634.0, 654.0], [2846.0, 1951.0], [3054.0, 1710.0], [2562.0, 1756.0], [2291.0, 1403.0], [2012.0, 1552.0], [682.0, 825.0], [518.0, 1251.0]
, [1332.0, 695.0], [4016.0, 1715.0], [4087.0, 1546.0], [4062.0, 2220.0], [4061.0, 2370.0], [4201.0, 2397.0], [3777.0, 2095.0], [3888.0, 2261.0], [3678.0, 2463.0], [3789.0, 2620.0], [3862.0
, 2839.0], [4263.0, 2931.0], [3492.0, 1901.0], [3479.0, 2198.0], [3318.0, 2408.0], [3296.0, 2217.0], [3394.0, 2643.0], [3101.0, 2721.0], [3792.0, 3156.0], [3143.0, 3421.0], [3130.0, 2973.0
], [2765.0, 3321.0], [2545.0, 2357.0], [2611.0, 2275.0], [2860.0, 2862.0], [2801.0, 2700.0], [2370.0, 2975.0], [1084.0, 2313.0], [4177.0, 2244.0], [3757.0, 1187.0], [3488.0, 1535.0], [3374
.0, 1750.0], [3326.0, 1556.0], [3258.0, 911.0], [3646.0, 234.0], [4089.0, 1387.0], [4196.0, 1044.0], [4312.0, 790.0], [4685.0, 830.0], [4720.0, 557.0], [4153.0, 426.0], [2831.0, 2099.0], [
3086.0, 1516.0], [2716.0, 1924.0], [2751.0, 1559.0], [1779.0, 1626.0], [1478.0, 267.0], [278.0, 890.0], [3715.0, 1678.0], [4181.0, 1574.0], [3929.0, 1892.0], [3751.0, 1945.0], [4207.0, 253
3.0], [4139.0, 2615.0], [3780.0, 2212.0], [3594.0, 2900.0], [3676.0, 2578.0], [4029.0, 2838.0], [3928.0, 3029.0], [4186.0, 3037.0], [3322.0, 1916.0], [3429.0, 1908.0], [3176.0, 2150.0], [3
229.0, 2367.0], [3402.0, 2912.0], [3402.0, 2510.0], [3468.0, 3018.0], [3356.0, 3212.0], [3044.0, 3081.0], [3140.0, 3550.0], [2769.0, 2492.0], [2348.0, 2652.0], [2778.0, 2826.0], [2126.0, 2
896.0], [1890.0, 3033.0], [3538.0, 3298.0], [3712.0, 1399.0], [3493.0, 1696.0], [3791.0, 1339.0], [3376.0, 1306.0], [3188.0, 1881.0], [3814.0, 261.0], [3583.0, 864.0], [4297.0, 1218.0], [4
116.0, 1187.0], [4252.0, 882.0], [4386.0, 570.0], [4643.0, 404.0], [4784.0, 279.0], [3007.0, 1970.0], [1828.0, 1210.0], [2061.0, 1277.0], [2788.0, 1491.0], [2381.0, 1676.0], [1777.0, 892.0
], [1064.0, 284.0], [3688.0, 1818.0], [3896.0, 1656.0], [3918.0, 2179.0], [3972.0, 2136.0], [4029.0, 2498.0], [3766.0, 2364.0], [3896.0, 2443.0], [3796.0, 2499.0], [3478.0, 2705.0], [3810.
0, 2969.0], [4167.0, 3206.0], [3486.0, 1755.0], [3334.0, 2107.0], [3587.0, 2417.0], [3507.0, 2376.0], [3264.0, 2551.0], [3360.0, 2792.0], [3439.0, 3201.0], [3526.0, 3263.0], [3012.0, 3394.
0], [2935.0, 3240.0], [3053.0, 3739.0], [2284.0, 2803.0], [2577.0, 2574.0], [2592.0, 2820.0], [2401.0, 3164.0], [1304.0, 2312.0], [3470.0, 3304.0])
Minimum distance: 34732.0
Time for Completion (seconds): 71.7
>>>
```

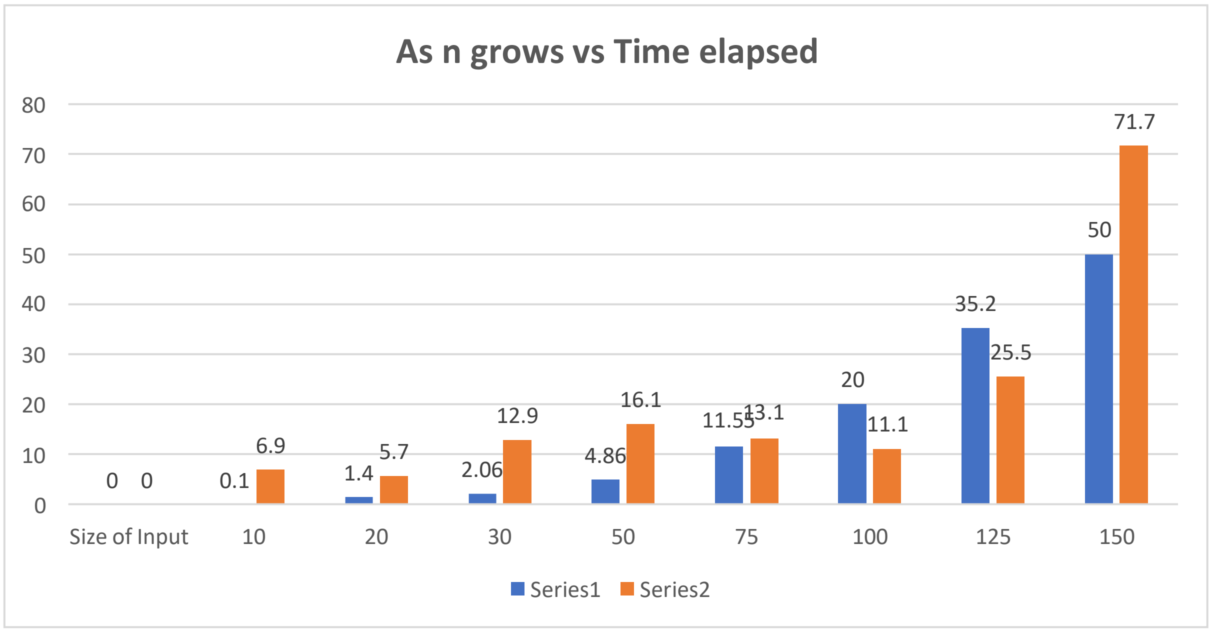
Graph depicting the route:



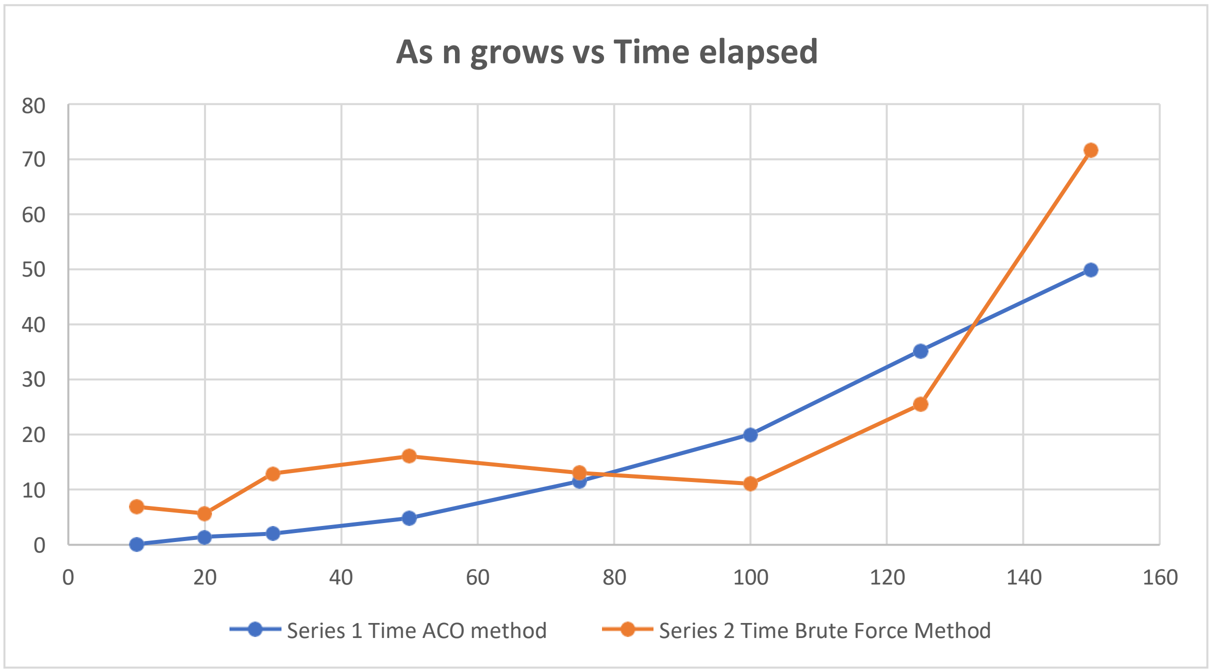
Comparison of Results from ACO and Brute Force Techniques – Table:

Size of Input(As n grows)	Time Elapsed in ACO method (Series 1)	Time Elapsed in Brute force method(Series 2)
10	0.1	6.9
20	1.4	5.7
30	2.06	12.9
50	4.86	16.1
75	11.55	13.1
100	20	11.1
125	35.2	25.5
150	50	71.7

Bar Graph:



Line Graph:



Conclusion:-

From the above table and the graphs drawn, we infer that **ACO is far better than brute force technique** when it comes to handle data to perform some computations.
We can see that for 150 inputs:
Time elapsed in ACO Technique – 49.7 sec
Time elapsed in Brute Force Technique – 71.7 sec

Bibliography(References):-

Base Papers :-

- An ant colony optimization method for generalized TSP problem
  Jinhui Yang a, Xiaohu Shi a, Maurizio Marchese b, Yanchun Liang a,*

- Ant colony optimization for real-world vehicle routing problems
  From theory to applications
  A.E. Rizzoli, · R. Montemanni · E. Lucibello · L.M. Gambardella

Websites Referred:-

- https://www.google.com/
- https://en.wikipedia.org/wiki/Travelling_salesman_problem
- https://stackoverflow.com/questions/5003400/travelling-salesman-problem

Book Referred:- Introduction to Algorithms
By:- Thomas H. Cormen ,Charles Leiserson, Ron Rivest, and Cliff Stein.

!!Thank You!!