ECE457A - Assignment 3, Question 3

By: Xiaotong Zhang & Swapan Shah

Part A

Iteration	(Population, diffusion, evaporation)	≈ Time to finish (ticks)
1	(30, 40, 10)	8069
2	(30, 40, 20)	7638
3	(30, 80, 10)	8250
4	(30, 80, 20)	8088
5	(50, 40, 10)	6116
6	(50, 40, 20)	5785
7	(50, 80, 10)	6498
8	(50, 80, 20)	6114
9	(100, 40, 10)	1582
10	(100, 40, 20)	3124
11	(100, 80, 10)	1934
12	(100, 80, 20)	3776

As expected, the pattern of food foraging by the ants depends on the distance between the food source and the starting location of the ants. As the simulation starts, the ants are scattered. With the progression of the algorithm, the pheromones will lead the ants to find the closest food source. Thus, the nearest food source is the first to deplete, and so on. It can also be observed that the amount of time to find and exploit a new food source increases with each further food location. It often takes much longer for the ants to deplete the furthest food source in comparison to the nearest.

From the data above, a few trends can be observed about the effects of population, diffusion, and evaporation on an ant colony search. As the size of the population increases, the amount of time it takes to finish decreases. With more ants foraging for food, more pheromones are deposited, allowing faster determination of the closest food source too all other ants.

As the evaporation rate increases, with all else equal, it takes a longer time for the algorithm to finish. With a higher evaporation rate, the established pheromones disappear more quickly and thus require ants to continually start over their search and deposit new pheromones that other ants will hopefully pick up on in time. However, this is not the case for smaller population sizes in which a higher evaporation rate allows the ants to finish faster.

As the diffusion rate increases, the amount of time it takes to finish increases as well. The changes in the evaporation rate and diffusion rate have a much greater impact on the finishing time for larger population sizes (e.g. population size of 100). With a lower diffusion rate, the pheromones are stronger for a longer period of time, allowing the ants to more easily follow the best paths to the nearest food source.

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Part B

1.0 Solution Description

The solution for the Ant Colony problem uses two classes, a "Location" class and an "AntColony" class in order to solve the problem. The Location class sets up all the cities that must be part of the travel. It initializes all the different coordinates and calculates the distances between each city. The AntColony class contains all functions required for initializing and updating the ants' trails and pheromone levels.

The main function initiates the algorithm with the required values of population, alpha, beta, rho, and Q (state transition control parameter). These variables are used throughout the program to calculate the probability of each move, as well as updating the pheromone levels both online and offline. Ants are initiated by allowing a set amount of population of ants to start at each possible city location (e.g. 10 ants will start at each city). The online pheromone update allows the pheromones to be updated at each step along the way and follows the traditional formulae

$$\tau_i = (1-\rho)\times\tau_i, \quad \rho \in (0,1]$$

$$\tau_{ij} = \tau_{ij} + \Delta\tau$$

The best solution is calculated every iteration, partially to allow for offline updates. Offline updates are done by increasing the pheromones levels along the shortest path travelled by the end of that iteration. The equation used for offline updates is

$$(1-\rho) + (Q / bestLength) * \rho .$$

The transition rule selected uses probabilities that are heuristically based using the following equation

$$p_{jk} = \begin{cases} \dfrac{[\tau_{jk}]^{\alpha}[\eta_j]^{\beta}}{\sum_{l\in T}[\tau_{lk}(t)]^{\alpha}[\eta_j]^{\beta}} & \text{if j} \in \text{T} \\ 0 & \text{otherwise} \end{cases}$$

This probability is taken and distributed evenly, allowing the next city to be chosen "randomly", although the city with the highest probability will also have a higher probability of being chosen. Having a heuristic based allows for the solution to be found more quickly as more knowledge is used to calculate it.

The stopping criterion is the number of iterations; in this case it is set to 5000.

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The simplified search algorithm is:

1) Initialize all cities and ants
2) Generate all required properties including trail, visited cities, and pheromones
3) Generate the first set of ants and their trails. The best solution and best distance should be calculated as well, as an initial benchmark (global best).
4) Check if termination conditions are met
5) If not, generate new trails for the ants and update all variables accordingly
6) Update the best solution if appropriate, as well as update the global best distance
7) Repeat steps 4-6 until termination conditions are met

2.0 Results

Sample Output:

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.005
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 22302.724

New best length found: 9480.319
New best length found: 8633.513
New best length found: 8574.956
New best length found: 8322.358
New best length found: 8234.746

Best Length Found 8234.746 at iteration 939

Best Trail Found:
20 | 01 | 12 | 09 | 19 | 03 | 14 | 13 | 17 | 16 | 21 | 10 | 18 | 24 | 06
| 15 | 26 | 23 | 07 | 27 | 00 | 05 | 11 | 08 | 04 | 25 | 28 | 02 | 22 |
```

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3.0 Analysis

3.1 Changing Pheromones (rho)

1) Pheromone persistence = 0.001

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.001
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 22310.216

New best length found: 9653.523
New best length found: 9356.384
New best length found: 9081.318
New best length found: 8774.026
New best length found: 8574.956
New best length found: 8549.535
New best length found: 8463.986
New best length found: 8407.992
New best length found: 8296.158

Best Length Found 8296.158 at iteration 3400

Best Trail Found:
04 | 28 | 25 | 08 | 05 | 11 | 27 | 00 | 20 | 01 | 19 | 09 | 03 | 14 | 17
| 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 | 26 | 07 | 23 | 15 | 12 | 02 |
```

2) Pheromone persistence = 0.008

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.008
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 22836.597

New best length found: 9475.438
New best length found: 8878.514
New best length found: 8864.441
New best length found: 8322.358
New best length found: 8199.094

Best Length Found 8199.094 at iteration 572

Best Trail Found:
20 | 01 | 12 | 09 | 19 | 03 | 14 | 13 | 17 | 16 | 21 | 10 | 18 | 24 | 06
| 15 | 23 | 26 | 07 | 27 | 00 | 05 | 11 | 08 | 04 | 25 | 28 | 02 | 22 |
```

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3) Pheromone persistence = 0.01

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.01
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 23640.226

New best length found: 9376.431
New best length found: 9345.84
New best length found: 8864.441
New best length found: 8489.362
New best length found: 8403.387
New best length found: 8197.605
New best length found: 8184.052
New best length found: 8086.261

Best Length Found 8086.261 at iteration 42

Best Trail Found:
02 | 28 | 25 | 04 | 08 | 05 | 11 | 27 | 00 | 20 | 01 | 19 | 09 | 03 | 14
| 17 | 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 | 26 | 07 | 23 | 15 | 12 |
```

It can be seen that as the pheromone persistence increases, the amount of iterations it takes to find the best length decreases significantly. With high persistence, the other ants have a longer period of time to recognize the better and shorter paths to travel.

3.2 Changing state transition control parameter (Q)

1) State transition control = 10

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.005
Q (State Transition) - 10

Initializing ant trails...

Best Initial trail length: 22215.095

New best length found: 9519.774
New best length found: 9292.015
New best length found: 8790.431
New best length found: 8432.247
New best length found: 8088.03

Best Length Found 8088.03 at iteration 35

Best Trail Found:
28 | 25 | 04 | 08 | 05 | 11 | 27 | 00 | 20 | 01 | 19 | 09 | 03 | 14 | 17
| 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 | 26 | 07 | 23 | 15 | 12 | 02 |
```

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2) State transition control = 500

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.005
Q (State Transition) - 500

Initializing ant trails...

Best Initial trail length: 20792.593

New best length found: 9526.051
New best length found: 9482.297
New best length found: 9128.649
New best length found: 9081.06
New best length found: 8941.773
New best length found: 8810.258
New best length found: 8290.975
New best length found: 8160.812

Best Length Found 8160.812 at iteration 175

Best Trail Found:
11 | 05 | 04 | 08 | 25 | 28 | 02 | 01 | 20 | 00 | 27 | 07 | 26 | 23 | 15
| 12 | 09 | 19 | 03 | 14 | 17 | 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 |
```

3) State transition control = 1,000

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.005
Q (State Transition) - 1000

Initializing ant trails...

Best Initial trail length: 22327.89

New best length found: 8721.402
New best length found: 8432.247
New best length found: 8088.03
New best length found: 8086.261

Best Length Found 8086.261 at iteration 19

Best Trail Found:
02 | 28 | 25 | 04 | 08 | 05 | 11 | 27 | 00 | 20 | 01 | 19 | 09 | 03 | 14
| 17 | 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 | 26 | 07 | 23 | 15 | 12 |
```

It can be seen that by increasing the state transition control parameter, the pheromones are spread much more quickly and increases more quickly along the better or shorter paths. As such, it should take less time for the

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3.3 Change population size

1) Population size = 50

```
TSP - Ant Colony

Population - 50
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.005
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 20067.926

New best length found: 8732.964
New best length found: 8407.992
New best length found: 8403.387
New best length found: 8333.564
New best length found: 8290.975
New best length found: 8199.128
New best length found: 8086.261

Best Length Found 8086.261 at iteration 45

Best Trail Found:
02 | 28 | 25 | 04 | 08 | 05 | 11 | 27 | 00 | 20 | 01 | 19 | 09 | 03 | 14
| 17 | 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 | 26 | 07 | 23 | 15 | 12 |
```

2) Population size = 100

```
TSP - Ant Colony

Population - 100
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.005
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 19801.546

New best length found: 8574.956
New best length found: 8290.975
New best length found: 8114.72
New best length found: 8088.03
New best length found: 8086.261

Best Length Found 8086.261 at iteration 12

Best Trail Found:
02 | 28 | 25 | 04 | 08 | 05 | 11 | 27 | 00 | 20 | 01 | 19 | 09 | 03 | 14
| 17 | 13 | 21 | 16 | 10 | 18 | 24 | 06 | 22 | 26 | 07 | 23 | 15 | 12 |
```

It can be seen that by increasing the population size, the amount of time it takes to find the shortest path decreases. With more ants traversing the different trails available, more pheromones can be accumulated and a greater variety of trails can be observed, aiding the ants to find the best trail

possible faster. It is also important to note that due to larger population, many more calculations are required to reach the solution and therefore the algorithm will take much longer.

3.4 No online pheromone update

Turning off the online pheromone update, this is a sample output:

```
TSP - Ant Colony

Population - 10
Alpha - 1
Beta - 5
Rho (Pheromone Persistence) - 0.001
Q (State Transition) - 2

Initializing ant trails...

Best Initial trail length: 21992.842

New best length found: 8641.522
New best length found: 8490.484
New best length found: 8449.65
New best length found: 8403.081
New best length found: 8401.312
New best length found: 8389.489
New best length found: 8272.336

Best Length Found 8272.336 at iteration 1646

Best Trail Found:
15 | 18 | 24 | 06 | 22 | 07 | 26 | 23 | 00 | 27 | 05 | 11 | 08 | 04 | 25
| 28 | 02 | 20 | 01 | 19 | 09 | 12 | 03 | 14 | 17 | 13 | 21 | 16 | 10 |
```

It can be seen that by taking away the online pheromone update, it takes much longer for the solution to be found due to the fact that pheromones are not updated as quickly or as much. All traveling is dependent on the update of the entire trail instead individual nodes or city connections.