“Ant Colony Optimization: The Traveling Salesman Problem”

Section 2.3 from *Swarm Intelligence: From Natural to Artificial Systems*
by Bonabeau, Dorigo, and Theraulaz

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Traveling Salesman Problem (TSP)

- Goal is to find a closed tour of minimal length connecting $n$ given cities.

- The problem can be thought of as a graph, with each city as a node and the paths between them as edges.
Traveling Salesman Problem

- Ant colony optimization approach to TSP was initiated by Dorigo, Colorni, and Maniezzo.
- The researchers chose the TSP for several reasons:
  - It is a shortest path problem to which the ant colony metaphor is easily adapted.
  - It is a very difficult (NP) problem.
  - It has been studied a lot and therefore many sets of test problems are available, as well as many algorithms with which to run comparisons.
  - It is a didactic problem: it is very easy to understand and explanations of the algorithm behavior are not obscured by too many technicalities.
Ant System (AS)

- Ants build solutions to TSP by moving on the problem graph from one city to another until they complete a tour.
- During an iteration of the AS algorithm each ant builds a tour executing one step for each node (city).
- For each ant, transitions from one city to another depend on:
  - Whether or not the city has been visited
  - The heuristic desirability ("visibility") of connected cities.
  - The amount of pheromone trail on the edge connecting two cities
Pheromone Trail

- At the end of a tour, each ant lays pheromones on each edge it has used.
- The amount of pheromone is proportional to the performance of the ant.
- Pheromones intensity on each edge decays over time.
Elitist Ants

- “Elitist” ants introduced to improve performance
- Elitist ants reinforce the edges belonging to the best tour found from the beginning of the trial
- Elitist ants are added at every iteration to reinforce the best path
AS Conclusions

- For small problems, AS performs comparably to other TSP algorithms.
- Quickly converged to good solutions for larger problems, but could not find optimal solutions.
- Performance level is much lower than specialized TSP algorithms.

<table>
<thead>
<tr>
<th></th>
<th>Best tour</th>
<th>Average</th>
<th>Std. Dev.</th>
</tr>
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<tbody>
<tr>
<td>AS-TSP</td>
<td>420</td>
<td>420.4</td>
<td>1.3</td>
</tr>
<tr>
<td>TS</td>
<td>420</td>
<td>420.6</td>
<td>1.5</td>
</tr>
<tr>
<td>SA</td>
<td>422</td>
<td>459.8</td>
<td>25.1</td>
</tr>
</tbody>
</table>

AS Conclusions

- Does not converge to a single optimal solution
- Continues to produce new, possibly improving, solutions
  - Avoids getting trapped in local optima
  - AS is promising for applications to dynamic problems
Ant Colony System (ACS)

- Improvements on Ant System made by Dorigo and Gambardella
- Based on four modifications of AS:
  - Different transition rule
  - Different pheromone trail update rule
  - Use local updates of pheromone trail
  - Use candidate list to restrict choices of next city
Transition Rule

- Uses a tunable parameter $q_0$ to adjust the probability that an ant will explore or reinforce existing paths
- Where $q > q_0$, ACS transition rule is identical to AS
- Where $q \leq q_0$, ACS exploits knowledge available about the problem (distances, existing pheromone trails, etc.)
- Gradually increasing $q_0$ would allow the algorithm to favor exploration early and existing paths afterward
Pheromone Trail Update Rules

- Only the ant with the best tour lays pheromones
- Encourages ants to search paths near the best found so far
Local Pheromone Trail Updates

- Each time an ant moves from one city to another, the pheromone concentration on that edge is reduced.
- This makes visited edges less attractive and encourages exploration.
Candidate List

- Candidate list is a list of preferred cities to visit from a given city.
- Unvisited cities in the candidate have priority over other cities.
FIGURE 2.15  (a) An example of a trail configuration found by ACS in a 50-city problem (Eil50). Line thickness reflects pheromone concentration. (b) Best solution found by ants.
ACS Conclusions

ACS performs comparably or better than other TSP algorithms.
Further Enhancements

- Added 3-opt procedure to locally minimize tour lengths between ACS iterations
  - Performed comparably with STSP algorithm that won the First Internation Contest on Evolutionary Optimization

- Other unimplemented improvements:
  - Allow the best r ants to update the pheromone trail, instead of a single ant
  - Remove pheromone from edges of worst tours
  - More powerful local search
Conclusions

- AS is more clearly swarm intelligent than ACS or ACS-3-opt
- Each version of the algorithm uses swarm behavior, but other aspects don’t fit the model of swarm intelligence
Questions?