Ant Colony Optimisation (ACO)

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With thanks to Marco Dorigo, Martijn Schut and Bruce MacLennan

Ant Colony Optimisation

- Invented by Marco Dorigo in 1991 (as part of his PhD thesis) in collaboration with Colomi and Maniezzo.
- Draws inspiration from the behaviour of real ants to provide a method of optimisation.
- Normally works with combinatorial optimisation problems e.g. TSP, scheduling, facility placement, but recently extended for use on real valued optimisation by Krzysztof Socha.

Real Ants

Movie thanks to Jean-Louis Deneubourg and Marco Dorigo

Ants – Shortest Path

- When walking the ants leave a pheromone trail
- When choosing a route they are more likely to follow a route which has more pheromone deposited
- When the first ants are returning home they will tend to find more pheromone on the shortest path
- The rules are probabilistic – so mistakes can be made
- Pheromones evaporate allowing changes if a locally minimal route is found.
Stigmergy

- Stigmergy is a particular kind of indirect communication exploited by social insects to coordinate their activities.
- “La coordination des tâches, la régulation des constructions ne dépendent pas directement des ouvriers, mais des constructions elles-mêmes. L’ouvrier ne dirige pas son travail, il est guidé par lui. C’est à cette stimulation d’un type particulier que nous donnons le nom de STIGMERGIE (stigma, piqure; ergon, travail, œuvre = œuvre stimulante).” Grassé P. P., 1959
- “[The coordination of tasks and the regulation of constructions does not depend directly on the workers, but on the constructions themselves. The worker does not direct his work, but is guided by it. It is to this special form of stimulation that we give the name STIGMERGY (stigma, sting; ergon, work, product of labour = stimulating product of labour).]”

Artificial Ants – Ant Colony Optimisation

- We can have a colony of artificial ants which lay a trail in the search space of some problem.
- The problem might involve finding a shortest path but might be something else entirely – like, for example, making the right decisions in the construction of a timetable.
- ACO uses artificial stigmergy.

Basic ACO Algorithm

- When making a decision in the construction of solution to a problem (e.g. which city to visit next, or where to timetable the next event), we choose from the set of possible choices probabilistically based on the amount of artificial pheromone associated with making that decision.
- When we have finished the construction we adjust the pheromones on the decision path that we have taken according to how good the solution is.
- As we construct more and more solutions there is more and more information available about the probable “right” choices to make.
- Usually many ants construct a solution at the same time (i.e. with the same pheromone set).
- Pheromone is allowed to evaporate to avoid being trapped in local optima.

Stigmergy

- Allows simpler agents
- Decreases direct communication
- When the environment changes the agents respond appropriately.
Example: Routing

Assume there is some algorithm to prevent loops and dead-ends

**Decision Making Example**

- The chance of taking choice 2 might be calculated like this:

\[
0.2 + 0.7 + 0.1 + 0.6 + 0.5 = 0.7
\]

\[
\tau_2 = \frac{0.333}{0.2 + 0.7 + 0.1 + 0.6 + 0.5}
\]

\[
\sum_{i} \tau_i
\]

**Adding Heuristic Information**

- We might like to add heuristic information about how to solve the problem.
  - E.g. for routing this might be the cost of an edge
  - The decision making process might take into account both the pheromone value and the heuristic value \( \eta \)
  - The probability of choosing path \( x \) becomes:

\[
\frac{\tau_2^\alpha \eta_2^\beta}{\sum_{i} \tau_i^\alpha \eta_i^\beta}
\]

- The relative values for alpha and beta determine the relative importance of the pheromones and the heuristic

<table>
<thead>
<tr>
<th>Choice</th>
<th>Variable Name</th>
<th>Pheromone Value</th>
<th>Chance of Choosing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( t_1 )</td>
<td>0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>2</td>
<td>( t_2 )</td>
<td>0.7</td>
<td>0.49</td>
</tr>
<tr>
<td>3</td>
<td>( t_3 )</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>4</td>
<td>( t_4 )</td>
<td>0.6</td>
<td>0.36</td>
</tr>
<tr>
<td>5</td>
<td>( t_5 )</td>
<td>0.8</td>
<td>0.64</td>
</tr>
</tbody>
</table>
Changing the Pheromones

The pheromone matrix will be updated by

- Each ant at the end of its route – depending on how good the route was
- Evaporation – usually after each set of ants has finished

TSP Demo

- [http://uk.geocities.com/markcsinclair/aco.html](http://uk.geocities.com/markcsinclair/aco.html)