Ant Algorithms

- Ants are social insects, living in colonies of 30 to million of individuals.
- They demonstrated complex collective behaviors:
  - Foraging
  - Division of labor
  - Cemetery organization and brood care
  - Construction of nests

Ant Colony Optimization

- Model of the foraging behavior of ants:
  - finding the shortest path between their nest and a food source.
- First algorithm was developed by Marco Dorigo in 1992.
- The algorithm has been extended and applied to different applications by various researchers.

Natural Ant Foraging Behavior

- At the beginning, all the ants follow their trails randomly.
- As soon as a food source is located, activity patterns become more organized with more and more ants following the same path to the food source.
- Soon, all ants follow the same, shortest path.

Communication via pheromone

- When an ant locates a food source, it carries a food item to the nest and lays pheromone along the trail.
- Ants are attracted by pheromone during forging.
- The shortest trail has the most pheromone because the ants return to the nest faster and come out again to get more food and deposits more pheromone.
- Pheromone evaporates with time.
- When food sources are exhausted and no more pheromone is deposited on the trail, ants move to other trails.
- Demo
Pheromone Concentration and Path Selection

- Forging ants decide which path to follow based on the pheromone concentration on the different paths.
- Paths with a larger pheromone concentration have a higher probability of being selected.

Autocatalytic Behaviors

A positive feedback about a trail become more attractive as more ants follow that trail.

Experimental Study

Even when the trails have the same length, due to random fluctuation in path selection, one will be chosen more often than the other (Deneubourg et al).

Stigmergy and Pheromone

- Stigmergy, a term coined by French biologist Pierre-Paul Grasse, means interaction through the environment.
- Two individuals interact indirectly when one of them modifies the environment and the other responds to the new environment at a later time. This is called stigmergy.
- The communication between ants through pheromone is a form of stigmergy.

Ants Inspired Algorithms

- There are a few versions of foraging behavior inspired algorithms:
  - Simple ACO by Dorigo, which was applied to shortest path and routing problems.
  - Ant System (AS) [Colorni, Dorigo and Maniezzo, 1991][Dorigo, Maniezzo, Colomi, 1996]
  - The ancestor of all Ant Colony Optimization Algorithms.

Ant System (AS)

- Applied to TSP
- Three Components:
  - A probabilistic transition rule to choose the path.
  - Memory (Tabu list) of previously visited nodes.
  - Pheromone depositing and updating.
Transition Rules on TSP

1. Transition from city i to j depends on:
   • Tabu list – list of cities previously visited.
   • heuristic $h_i = d_{ij}$; represents local information, the desirability to visit city j when in city i.
   • Pheromone trail $\tau_{ij}(t)$ for each edge – represents the learned desirability to visit city j when in city i.
2. Generally, have several ants searching the solution space.

Probabilistic Transition Rule

- Probability of ant $k$ going from city i to j:
  $$p_{ij}^k(\tau) = \frac{[\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum_{\{j': j' \neq j\}} [\tau_{ij'}(t)]^{\alpha} \cdot [\eta_{ij'}]^{\beta}}$$

- $\eta$ is an heuristic evaluation of edge $(i,j)$ which introduces problem specific information in the TSP, the typical choice is the inverse of the edge length.
- $\tau_{ij}$ is the amount of pheromone trail on edge $(i,j)$
- $J^i$ is the set of cities ant $k$ positioned in city $i$ still has to visit (based on a Tabu list)

Probabilistic Transition Rule - Continue

- $\alpha$ and $\beta$ are adjustable parameters.
- A high value for $\alpha$ means that pheromone concentration is very important;
  - Ants tend to choose edges chosen by other ants in the past
- A high values of $\beta$ means that the distance to other cities is very important;
  - Ants tends to choose the closest city
- $\alpha = 0$: represents a greedy (select the closest city) approach;
- $\beta = 0$: represents selection of the currently most visited tour, which may or may not be optimal.
- Thus, a tradeoff is necessary.

Pheromone Evaporation

- After all $k$ ants have built a tour, pheromone on all edges $(i,j)$ evaporates as the following:
  $$\tau_{ij}(t + 1) = (1 - \rho) \cdot \tau_{ij}(t)$$
  Where $\rho \in (0,1)$ defines the evaporation rate

Pheromone Deposit

- Additionally, pheromone is deposited on each edges $(i,j)$:
  $$\Delta \tau_{ij}(t) = \sum_{k=1}^{k} \Delta \tau_{ij}^k(t)$$
  where quality$^k$ is set proportional to the inverse of the length of the solution found by ant $k$ $(\frac{1}{x_i})$

Example

- particle permutation: fitness
- $a$ c a f e b d 31.57401
- $b$ d b a f e 28.95417
- $c$ f d a b e c 31.04489
- $d$ b d f e a c 31.57401
- $e$ c d e b a f 27.6283

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AS on TSP Results

- Does not perform as well as other methods – the ones mentioned are TS (Tabu Search) and Simulated Annealing.
- Does not converge to a single solution – is that a good thing?
- However, they conclude that the “non-convergence” property is interesting:
  - It tends to avoid trappings in local optima.
  - Could be used for dynamic problems.
- So next …..Ant Colony System