Jean-Philippe Rennard 02/2003
http://www.rennard.org/alife -- alife@rennard.org

Social insects and self-organization

An ant is quite a simple animal. Its behavioral repertory is limited to ten to forty elementary behaviors. Yet, anthills are very complex. One can find nursery, warehouses or kitchen gardens. Some individuals forage, others take care of the eggs, repair the nest or protect the anthill against miscellaneous threats. What is the mystery, how can so mindless animals achieve such a complex organization?

Division of labor could be the key. Ants are highly specialized, so specialized that some individuals have to be fed by others, they are unable to get food by themselves. In economy, division of labor means efficiency, but to work properly, it supposes some supervision, the different tasks have to be coordinated. Yet such a supervisor doesn't exist in anthills, no ants (and particularly not the queen) are able to manage this exploit. Nevertheless, the coordination necessarily exists; it results from some self-organization process.

Let us examine foraging strategies in ants to exemplify this idea.

At the beginning, a number of ants are walking, more or less randomly outside the nest. They are looking for food. All along their way, they deposit a light trail of pheromones. When an ant finds some food, it gets back home, deposing a stronger trail (the intensity of the trail possibly depends on the richness of the found resource). Since ants have trail-following behavior, a growing number of individuals will tend to follow it and to reach the food. When they get back, they reinforce the trail. A positive feedback (auto-amplification) therefore appears, more individuals reinforce the trail, attracting new individuals which will at their turns reinforce the trail…

In this example, the ants don't communicate directly. Information are exchanged through modifications of the environment (here local gradients of pheromones). This type of communication is known as *stigmergy*. This concept was proposed by P.P. Grassé in 1959. Studying the nest reconstruction in termites, Grassé showed that it doesn't rely on direct communications between individuals. The nest structure itself coordinates the workers tasks essentially through local pheromones concentrations. The state of the nest structure triggers some behaviors which then modify the nest structure and triggers new behaviors until the construction is over. The process is similar in ants foraging.

The ants tend to follow pheromones trails, but it is only an inclination. There is at any time a positive probability for the ant to abandon the trail and to move more or less randomly. It is then possible that the "lost" ant finds a new resource, eventually far richer than the one that was previously exploited. By constructing a new trail, this ant will attract new individuals and a new positive feedback loop will be set up.

Finally, when satiety occurs or when the resource is empty a negative feedback loop appears. For example, if pheromone decay is quick enough, when the resource is over, less and less ants will tend to follow the trail which will progressively disappear.

Self-organization in social insects is interpreted through four main mechanisms [1] :

1. The existence of *multiple interactions*.
2. Amplification through *positive feedback*.
3. *Negative feedback*.
4. A*mplification of fluctuations*. In the previous example, the fluctuation is the fact that an ant abandon the pheromones trail; it is amplified by the positive feedback loop which then occurs.

Ants foraging process in some species have been analyzed by J.-L. Deneubourg [2] (Université Libre de Bruxelles). He notably showed how ants can find the best (shortest) way to reach a resource. In a simplified manner, the accumulation of pheromones is faster on the shortest way, positive feedback therefore privileges it.

On these basis, M. Dorigo proposed the concept of "Ants Colony Optimization" (ACO). He applied this process to travelling salesman problem and then extended it to a whole class of optimization problems. Such algorithms can now be found in telecommunications routing, the design of electronic circuits or — for example — the organization of industrial process.

Jean-Philippe Rennard 02/2003
http://www.rennard.org/alife -- alife@rennard.org

1. BONABEAU E., DORIGO M., THÉRAULAZ G.,*Swarm Intelligence. From Natural to Artificial Systems*, Oxford University Press, 1999, p. 8-14.
2. See for example : DENEUBOURG J.-L. et *al.*, « Plan d'organisation et population dans les sociétés d'insectes », p. 141-155, dans PRIGOGINE I. (dir.), *L'homme devant l'incertain*, Paris, Odile Jacob, 2001.