

## A Study of Swarm Intelligence

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### Abstract

In this paper we illustrate total structure of swarm intelligence and their impacts on net-centric computing environments. The paper presents a comprehensive look on swarm applications and its potential to solve complex problems in related areas. The effects of emergent externalities of swarm behavior through its basic elements such as groups/clusters, individuals/agents and inner/outer communications are also studied to explain the role of swarming in improving the performance of net-centric systems. Self-organization, introduced as results of such collective and cooperating strategies. The paper also takes a look at the role of existing technologies and related challenges towards implementing real swarm systems.

### Introduction

Swarm intelligence (SI) is an artificial intelligence<sup>1</sup> technique based around the study of collective behavior in decentralized, self-organized systems. The expression “swarm intelligence” was introduced by Beni & Wang in 1989, in the context of cellular<sup>5,6</sup> robotic systems SI systems are typically made up of a population of simple agents interacting locally with one another and with their environment. Although there is normally no centralized control structure dictating how individual agents should behave, local interactions between such agents often lead to the emergence of global behavior. Examples of systems like this can be found in nature, including ant colonies, bird flocking, animal herding, bacteria molding and fish

schooling.

*Swarm Intelligence (SI)* is the property of a system whereby the collective behaviors of (unsophisticated) agents interacting locally with their environment cause coherent functional global patterns to emerge. SI provides a basis with which it is possible to explore collective (or distributed) problem solving without centralized control or the provision of a global model. The swarming behavior of ants, bees, termites, and other social insects has implications far beyond the hive. Swarm intelligence — the collective behavior of independent agents, each responding to local stimuli without supervision — can be used to understand and model phenomena as diverse as blood clotting, highway traffic patterns, gene expression, and

immune responses, to name just a few. Swarm technology is proving useful in a wide range of applications including robotics and nanotechnology, molecular biology and medicine, traffic<sup>7</sup> and crowd control, military tactics, and even interactive art. In nutshell, Swarm Intelligence is an artificial intelligence technique based on the study of collective behavior in self-organized systems.

Swarm Intelligence systems are typically made up of a population of simple agents interacting locally with one another and with their environment. This interaction often lead to the emergence of global behavior. The main bio-inspired algorithms that have been developed are:

- **Ant Colony Optimisation (ACO)**
- **Particle Swarm Optimisation (PSO)**
- **Bird Flocking**

#### Natural Ants

- Individual ants are simple insects with limited memory and capable of performing simple actions.
- However, an ant colony expresses a complex collective behavior providing intelligent solutions to problems such as:
  - carrying large items
  - forming bridges
  - finding the shortest routes from the nest to a food source, prioritizing food sources based on their distance and ease of access.

Moreover, in a colony each ant has its prescribed task, but the ants can switch tasks if the collective needs it.

Outside the nest, ants can have 4 different tasks:

*Foraging*: searching for and retrieving food  
*Patrolling*: looking for food supply  
*Midden work*: Sorting the colony refuse pile  
*Nest maintenance work* : construction and clearing of chambers

An ant's decision whether to perform a task depends on:

The Physical State of the environment.  
 If part of the nest is damaged, more ants do nest maintenance work to repair it. Social Interactions with other ants

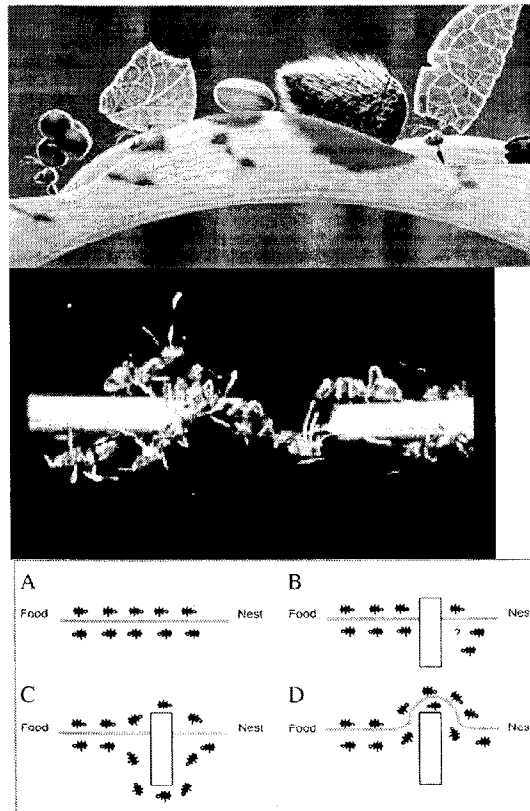


Figure 2. A. Ants in a pheromone trail between nest and food; B. an obstacle interrupts the trail; C. ants find two paths to go around the obstacle; D. a new pheromone trail is formed along the shorter path.

*Social Insects achieve self-organization through communication*

Two types of communication techniques are used by them:-

- *Direct*: antennation, trophallaxis (food or liquid exchange), mandibular contact, visual contact, chemical contact, etc.
- *Indirect*: 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.

Procedure of performing the task by natural ants:

- When ants meet, they touch with their antennae that are organs of chemical perception.
- An ant can perceive the colony-specific odor that all nest mates share.
- In addition to this odor, ants have an odor specific to their task, because of the temperature and humidity conditions in which it works.
- So that an ant can evaluate its rate of encounter with ants of a certain task.
- The pattern of interaction each ant experiences influences the probability it will perform a task.

*Finding shortest path:* "The best possible way for ants to find anything is to have an ant everywhere all the time, because if it doesn't happen close to an ant, they are not going to know about it. Of course there are not enough ants in the colony, so the ants have to move around in a pattern that allows them to cover space efficiently"

They establish indirect communication system based on the deposition of pheromone over the path they follow.

An isolated ant moves at random, but when it finds a pheromone trail, there is a high

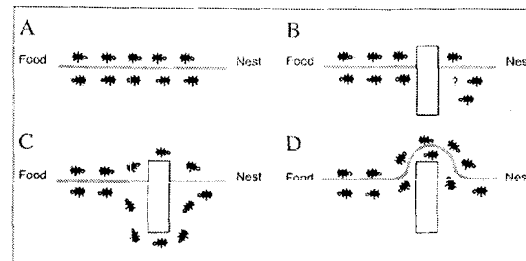


Figure 2. A. Ants in a pheromone trail between nest and food: B. an obstacle interrupts the trail; C. ants find two paths to go around the obstacle; D. a new pheromone trail is formed along the shorter path.

probability that this ant will decide to follow the trail. An ant foraging for food deposits pheromone over its route. When it finds a food source, it returns to the nest reinforcing its trail. So, other ants have greater probability to start following this trail and thereby laying more pheromone on it. This process works as a positive feedback loop system because the higher the intensity of the pheromone over a trail, the higher the probability of an ant start traveling through it.

Since the route B is shorter, the ants on this path will complete the travel more times and thereby lay more pheromone over it. The pheromone concentration on trail B will increase at a higher rate than on A, and soon the ants on route A will choose to follow route B. Since most ants will no longer travel on route A, and since the pheromone is volatile, trail A will start evaporating. Only the shortest route will remain.

#### *Modeling Ants Colony :*

It is known that the ability of ants in finding the shortest route between the nest and a food source can be used to solve graph

problems.

*Environment:*

Actions that an agent performs:

- In a city, it chooses a route based on the intensity of the pheromone over the available paths.
  - When it finds the food source, it starts the return travel on its own pheromone trail
- All actions require only local information and short memory.

### *Ant Colony Optimization :*

Optimization Technique Proposed by Marco Dorigo in the early '90

Each artificial ant is a probabilistic mechanism that constructs a solution to the problem, using:

- Artificial pheromone deposition
- Heuristic information: pheromone trails, already visited cities memory ...

Differences between real and artificial ants:

- Artificial ants live in a discrete world
- The pheromone is updated only after a solution has been constructed.

Additional mechanisms

### *Construct Ant Solutions*

- The exact rules for the probabilistic choice of solution components vary across different ACO variants.

### *Update Pheromones*

It is used to increase the pheromone<sup>7</sup> values associated with good or promising solutions, and decrease those that are associated with bad ones.

Decreasing all the pheromone values

through *pheromone evaporation* -> allows “forgetting” -> favors exploration of new areas

Increasing the pheromone levels associated with a **chosen set** of good solutions -> makes the algorithm converge to a solution

$S_{upd}$  is the set of solutions that are used for the update

$\rho$  (0; 1] is a parameter called evaporation rate

$F$  is a function commonly called the *fitness function*.

$$\tau_{ij} \leftarrow (1 - \rho) \cdot \tau_{ij} + \rho \cdot \sum_{s \in S_{upd} | c_{ij} \in s} F(s)$$

Different ACO algorithms differ in the way they update the pheromone.

*AS-update:*  $S_{upd} = S_{iter}$  (the set of solutions that were constructed in the current iteration) -> Like in Nature

*IB-update:*  $S_{upd} = S_{ib} = \arg \max F(s)$  (*iteration-best* solution: the best solution in the current iteration).

- introduces a much stronger bias towards the good solutions -> increases speed
  - Increases the probability of premature convergence

*BS-update:*  $S_{upd} = S_{bs}$  (*best-so-far* solution: the best solution since the first algorithm iteration)

- Introduces an even stronger bias

In practice, ACO algorithms that use variations of the IB-update or the BS-update rules and that additionally include mechanisms to avoid premature convergence, achieve better results than those that use the AS-update rule.

### Modeling Bird Flocking:

The synchrony of flocking behavior is thought to be a function of bird's efforts to maintain an optimal distance between themselves and their neighbors. "Individual members can profit from the discoveries and previous experience of other members during the search for food. This advantage can become decisive, outweighing the disadvantages of competition for food"

Birds and fish adjust their physical movement to avoid predators, seek for food and mates.

Humans tend to adjust our beliefs and attitudes to conform with those of our social peers. Humans change in abstract multidimensional space, collision-free.

#### Definitions:

Flock is a group of objects that exhibit the general class of polarized (aligned), non-colliding, aggregate motion.

Boid is a simulated bird-like object, *i.e.*, it exhibits this type of behavior. It can be a fish, bee, dinosaur, etc.

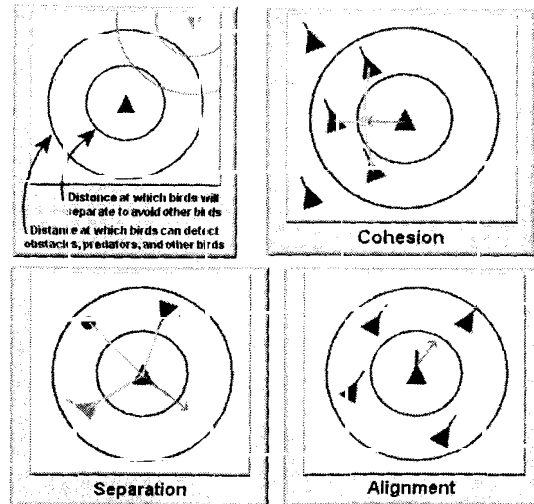
#### Rules for flocking:

**Cohesion:** Each boid fly towards the centroid of its local flock mates (that is, boid in its local neighborhood)

**Separation:** Each boid keep a certain distance away from local flock mates to avoid collisions

**Alignment:** Each boid align its velocity vector and keep velocity magnitude similar with that of the local flock

**Note:** There might be many other rules for making the flock more realistic.



#### Applications

Swarm technology is particularly attractive because it is

Cheap  
Robust  
Simple

#### Some examples of applications:

Controlling unmanned vehicles, Possibility of using it to control nanobots within the body to kill cancer tumors, Disney's The Lion King was the first movie to make use of swarm technology (the stampede of the wildebeest's scene). The Lord of the rings used it too during the battle scenes. Grid Data Replication

#### Future scope of work:

At present, Swarm Engineering is an emerging field, with a growing number of people interested in the techniques. There are many questions to be answered, particularly in the area of classification of swarm-based tasks and general methods. To date, there have been several different task areas identified, including deliberate and stigmergic communication, distributed recruitment, sensor fusion, distributed computation, and medical uses of

swarms. It is currently unknown if the number of different areas in which swarms have been applied is exhaustive. A catalog of methods for each of these areas needs to be built up so that it may be possible to choose from one of many different methods when designing an application. More effort must be focused on work which provably describes swarm behaviors. This is likely to lead the field in directions that are currently out of the reach of our current methodologies and expectations.

### Conclusions

Robots are a perfect platform to study the principles of self-organization in a precisely controlled environment. Biologists often observe the behavior of focal animals and analyze the positive and negative feedback loops that lead to self organization. By using robot swarms, one can transfer these feedback loops into robots with a well known program and one can place these robots in a controlled environment. The use of artificial neural networks and especially the use of evolutionary processes to shape these networks make these platforms even more interesting for understanding and for teaching biological processes. We can learn from nature and take advantage to solve the problems that they have already solved. Many simple individuals interacting with each other can make a global behavior emerge. Techniques based on natural collective behavior (Swarm Intelligence) are interesting as they are cheap, robust, and simple. They have lots of different applications. Swarm intelligence is an active field in Artificial Intelligence, many studies are going on.

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