Chapter 16

Pheromone-Style Communication for Swarm Intelligence

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ABSTRACT

Pheromones are the important chemical substances for social insects to realize cooperative collective behavior. The most famous example of pheromone-based behavior is foraging. Real ants use pheromone trail to inform each other where food source exists and they effectively reach and forage the food. This sophisticated but simple communication method is useful to design artificial multiagent systems. In this chapter, the evolutionary pheromone communication is proposed on a competitive ant environment model, and we show two patterns of pheromone communication emerged through co-evolutionary process by genetic algorithm. In addition, such communication patterns are investigated with Shannon’s entropy.

INTRODUCTION

Swarm intelligence is a type of artificial intelligence based on the collective behavior of decentralized, self-organized systems (Dorigo & Theraulaz, 1999). The knowledge and information processors in swarm intelligence are widely decentralized in parts of the system, which are called agents. All agents basically have a decision-making mechanism obtained from local knowledge, by local-information processing, and from communication channels with cooperative agents.

Swarm behavior is the aggregation of such local interactions. The usability of multi-agent systems and swarm intelligence is well-known in various applications in robotics, optimization problems, distributed computing, Web services, and mobile technologies. The main topic of such applications has always been how to design local agents that will emerge to demonstrate sophisticated global behavior. We can only design local behavior by implementing agents, although we need sophisticated global behavior. To obtain good designs, we must understand the relationship between local design and emerging results.

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One good way of introducing such relationships is provided by nature. Real ants and bees are called social insects. Their colonies consist of many members who attend to various jobs to preserve the life of each colony (Sheely, 1995). The sizes of colonies are much too large for members, even queens, to comprehend all activities and information. In other words, although individual abilities to assess the condition of each colony are limited, they can still do their work based on this limited information. The total activities of colonies, e.g., defense against enemies, repairing nests, childcare, and foraging, emerge due to the aggregation of such individual behaviors. Moreover, colonies must balance out the total work appropriately according to changes in the situation to optimize their operating costs. It is easy to see that communication between members is very important to attend to the many matters that each colony requires.

Many species of social insects not only have direct- but also indirect-communication channels that are equally important attained by using special chemical substances, which are called “pheromones.” (Agosta, 1992) A pheromone is a chemical that triggers a natural behavioral response in another member of the same species. When one member of an ant colony senses a particular internal condition or external stimulus, it responds to such a situation and it releases a corresponding kind of pheromone into the environment. The pheromone is diffused through the environment by natural characteristics, e.g., evaporation from the ground, diffusion in the air, and physical contact between the members or the members and their enemies. By using the effect of such translation from the sender to the environment, the pheromone signal sends not only a message from the sender but also information about the current environment. When the receiver senses such a pheromone, it causes a particular reaction in the receiver due to the natural characteristics of the species. One kind of honeybee handles over thirty types of pheromones, which include alarm pheromones for warnings about enemy attacks, Nasanov pheromones for gathering their mates, and queen pheromones as a signal to indicate the queen is alive.

A good example enabling the relationship between pheromone communication and swarm intelligence to be understood is the foraging behavior of real ants. In the first stage of typical ant-foraging behavior, scouting worker ants individually begin searching for routes from the nest in random directions. When a scouting worker discovers a food source along the route, it picks up the food and brings it back to the nest while laying down a pheromone. Consequently, it releases the first pheromone trail on the ground from the food source to the nest. The pheromone trail plays an important role in collective foraging behavior. If other workers around the nest find the pheromone trail, they try to follow it to arrive at the food source. These workers also discover the food source and then return to the nest while reinforcing the intensity of the pheromone trail. The intensity of the pheromone trail is successively reinforced by the large numbers of workers who continue to march to the food source until all the food is consumed. No ants reinforce the pheromone trail after they have removed all the food. The pheromone gradually evaporates from the ground and the trail automatically dissipates into the air.

This type of sophisticated collective behavior can emerge due to the complex effect of local decision-making, pheromone-communication channels, and natural characteristics of the environment. The mechanism based on such complex effects is called “stigmergy” in the research area of ethology. In the pheromone mechanism of stigmergy, a member releases a pheromone into the environment, which interferences with its propagation, and the other members detect the pheromone from the environment. This communication channel enables the entire colony to organize all of its members and achieve high-level tasks that require coordination and decentralization between them (Dorigo & Theraulaz, 1999).