Chapter II
Multi-Cellular Techniques

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ABSTRACT

Social insects—ants, bees, wasps, and termites—and the distributed problem-solving, multi-agent paradigm that they represent, have been enormously influential in nature-inspired computing. Insect societies have been a source of inspiration and amazement for centuries, but only in the last 25 years or so have we made significant inroads to both understanding just how various collective phenomena arise and are governed, and how we can use the lessons and insights garnered from sociobiological research for more practical purposes. In this chapter, we provide a very brief history of the field, detailing some of the key phenomena, mechanisms, and lessons learned, and a quick tour of some of the different types of applications to which this knowledge has been put to use, including but certainly not limited to distributed problem solving, task allocation, search, and collective robotics.

ARTIFICIAL LIFE

Insect societies owe their illustriousness, in part, to their ubiquity (they are found on every continent except Antarctica) and that almost all of us, at one time or another, has had some food item discovered by a single foraging ant, and only a few moments later we witness the arrival of a whole group—then a trail—of nestmates, ready to carry off the spoils. Move the food, and the trail quickly adapts to the new location. More concretely, provide a colony of certain ant species with a choice of two food sources, say a weak sugar solution and a strong sugar solution, and the colony will select a trail to the better source, moreover, without a single ant ever visiting both food sources (Camazine et al., 2001, and references therein). Watch a trail over time and it can become straighter, and thus more efficient, again without any individual having a global view of the situation (Bruckstein, 1993; see Shao & Hristu-Varsakelis, 2005, for an application). Peer inside a colony and you will find many different tasks being performed concurrently (cleaning, feeding larvae, processing food, etc.), each task with the appropriate number of individuals to meet that task's demands. Remove some of the individuals tackling one of the tasks, and the allocation of workers across the colony will shift to redress the balance (Wilson, 1984). Just how can a colony of these tiny creatures, with necessarily small brains, achieve such amazing, adaptive collective behavior?

People have long pondered this very question, perhaps summed up best by Maeterlink (1927): “What is it that governs here? What is it that issues orders, foresees the future, elaborates plans and preserves equilibrium, administers, and condemns to death?” Many have assumed that it is the queen herself that directs the colony’s activities (and in some cases, that it is the relatively inactive ant soldiers, with their larger heads, who direct traffic on trails) (Step, 1924; Ewers, 1927). However, this would require both a sophisticated communication system and a remarkable cognitive ability on the part of the queen to collate all the necessary information, process it, devise some plan of action, and pass those orders back to the workers. The reality is that while there exists some degree of queen control, especially in very small insect societies, this mostly relates to reproductive rights, the queen maintaining her reign. Quotidian tasks such as foraging, cleaning, and nest construction are regulated in a very *distributed* manner relying on direct individual-to-individual interactions or indirect “stigmergic” interactions (Grassé, 1959) mediated through the environment (e.g., ants that lay trail pheromone that influences the foraging behavior of other ants) (e.g., Hölldobler & Wilson, 1990; Camazine et al., 2001).

While careful methodical experimentation and detailed mathematical models have helped elucidate some of the proximate mechanisms at work, the popularization of insect societies as a powerful metaphor and new paradigm among the artificial intelligence community owes much to the field of artificial life. (Although we should not forget Hofstadter’s 1980 highly influential and Pulitzer prize winning book, *Gödel, Escher and Bach*, in which, in one chapter, “Ant Fugue,” he uses an ant colony as a metaphor for the mind.) A-life, a field of artificial biology (usually) using computer simulation to model “life as it is,” to explain extant biological phenomena, or “life as it could be,” to explore life’s possibilities, began in the 1980s. Of particular relevance is one of the seminal models in the field and one of the earliest models of ants. Langton’s virtual ants or “vants” (Langton, 1986) are absurdly simple: there is a grid of cells that may be black or white and one or more ants; an ant that lands on a black cell turns the cell white, turns right and moves forward one unit; an ant that lands on a white cell turns the cell black, turns left and moves forward one unit. Despite the apparent triviality of this system, what arises is surprising: ants may mill around in a seemingly chaotic fashion, but in certain situations may interact with each other, mediated through the color of the cells, to form “highways” (see Figure 1) and move the ants in a coordinate fashion across the grid.

It is computer experiments such as these that fired up the imaginations of many researchers and triggered a slew of ant-based simulations that formed the basis for this subfield of nature-inspired computing. This approach of abstracting such systems almost to the point of absurdity, and yet still retain incredibly complex and surprising behavior, seems to have been key in eradicating the mysticism that surrounds many complex systems. Here was a trivial, deterministic system in which all local rules and behavior are known, and yet the long-term collective behavior was in most cases unpredictable from a given set of initial conditions. (In fact, vants is a four-state, two-dimensional Turing machine; Weisstein, 2005.) Now one possessed a mini-world in which one could explore initial conditions and other parameters, and by use of careful experimentations stood a

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