Chapter 4
Initial Formulation of an Optimization Method Based on Stigmergic Construction

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ABSTRACT
Sign-based stigmergic methods such as the ant colony optimization algorithm have been used to solve network optimization, scheduling problems, and other optimization problems that can be visualized as directed graphs. However, there has been little research focused on the use of optimization methods based on sematectonic stigmergy, such as coordination through collective construction. This paper develops a novel approach where the process of agent-directed stigmergic construction is introduced as a general optimization tool. The development of this new approach involves adopting previous work on stigmergic construction to a virtual space and applying statistical mechanics–based techniques to data produced during the stigmergic construction process. From this a unique procedure for solving optimization problems using a computational procedure that simulates sematectonic stigmergic processes such as stigmergic construction is proposed.

BACKGROUND AND MOTIVATION
Stigmergy is a form of implicit communication through the environment, used for instance by social insects, to perform collective tasks (Theraulaz & Bonabeau, 1999). Wilson (2000) identified two forms of stigmergy: 1) sematectonic stigmergy and 2) sign- or marker-based stigmergy. Sematectonic stigmergy involves communication through modifications to a physical environment, whereas sign-based stigmergy involves communication via a signaling mechanism. Sematectonic stigmergy can be represented by examples such as the formation of trails (e.g., worn-down grass on frequently used routes), structure building by termites, and wasp nest construction. An example

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for sign-based stigmergy is the phenomenon of ants laying down pheromones as they search for food. Ants follow pheromone-containing paths with greater probability, and the pheromones accumulate (even as earlier laid pheromones evaporate) as more ants travel on that path. Both forms of stigmergy consist of two classes of stigmergic mechanisms: quantitative and qualitative (Theraulaz & Bonabeau, 1999). 

Consider an example of sematectonic stigmergy: termite arch building initially involves a group of termites that pick up mud pellets, inject a pheromone into them and deposit them at random locations. The next group of termites then deposit more mud pellets near and on the already existing pheromone concentrations. The mud heaps grow into columns and the columns tend to grow towards each other as the pheromones on the bottom evaporate. This process is quantitative or continuous stigmergy because the stimulus in the environment does not change; however, the amount of the stimulus can change and result in different responses (or probability of response) to the stimulus.

In contrast to termite arch building, during wasp nest construction the wasps deposit new nest elements on a lattice consisting of existing nest elements and available sites, depending on local observations of the existing nest arrangement. This process can be termed qualitative or discrete stigmergy because the wasps respond to a series of local rules or a discrete set of qualitatively different stimuli that result in different responses.

Several sources have used stigmergic optimization based on either the ant colony optimization algorithm (sign-based stigmergy) or particle swarm optimization techniques to solve control and optimization problems (Abraham, Grosan, & Ramos, 2006). Recent reviews of metaheuristic algorithms or nature-inspired methods have not mentioned optimization techniques based on qualitative sematectonic stigmergic methods (Blum, Aguilera, Roli, & Sampels, 2008; Bianchi, Dorigo, Gambardella, & Gutjahr, 2009).

MODELING STIGMERGIC CONSTRUCTION

Assembled structures can emerge from numerous local interactions between the components or agents in a given environment. The motivation behind modeling stigmergy based collective construction is based on observations of paper wasps that build their nests by engaging in reactive, stimulus-response type behaviors. Although they may not have any explicit knowledge about the overall structure of the nest they are building, they can observe the local arrangements of existing nest elements. This observation leads to the insect behavior or response regarding depositing a new nest element. The local patterns that lead the insect to engage in a reactive behavior were termed stigmergic configurations by Theraulaz and Bonabeau (1995), who also performed a computational study of the nest construction of paper wasps. In their study the modeled wasps moved randomly in a three-dimensional lattice and reacted to stigmergic configurations when they were close enough to detect one. Theraulaz and Bonabeau designed the stigmergic configurations or rule sets manually. In a later study by Bonabeau, Guerin, Snyers, Kuntz, and Theraulaz (2000) the rule sets were evolved using a genetic algorithm.

Modeling of collective construction usually involves mobile agents carrying building blocks to the structure under construction and placing them at the appropriate sites. The collective construction process is also identical to self-assembly where the blocks being assembled are themselves the mobile agents (Jones & Matarić, 2003). To extend the construction of simple structures (such as built by paper wasps) to more complex and arbitrarily shaped pre-specified structures using mobile agents that assemble or carry blocks for assembly, the mobile agents are given a finite state machine and decentralized, local agent rules for shape formation. This extension of the functional capacity of the agents has been termed extended stigmergy by Werfel and Nagpal (2006).