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Stigmergic epistemology, stigmergic cognition

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Abstract

To know is to cognize, to cognize is to be a culturally bounded, rationality-bounded and environmentally located agent. Knowledge and cognition are thus dual aspects of human sociality. If social epistemology has the *formation, acquisition, mediation, transmission* and *dissemination* of knowledge in complex communities of knowers as its subject matter, then its third party character is essentially stigmergic. In its most generic formulation, stigmergy is the phenomenon of *indirect communication mediated by modifications of the environment*. Extending this notion one might conceive of social stigmergy as the extra-cranial analog of an artificial neural network providing *epistemic* structure. This paper recommends a stigmergic framework for social epistemology to account for the supposed tension between individual action, wants and beliefs and the social corpora. We also propose that the so-called "extended mind" thesis offers the requisite stigmergic cognitive analog to stigmergic knowledge. Stigmergy as a theory of interaction within complex systems theory is illustrated through an example that runs on a particle swarm optimization algorithm.

Keywords: Stigmergy; Social epistemology; Extended mind; Social cognition; Particle swarm optimization

1. Introduction

To know is to cognize, to cognize is to be a culturally bounded, rationality-bounded and environmentally located agent.[1] Knowledge and cognition are thus dual aspects of human sociality. If social epistemology has the formation, acquisition, mediation, transmission and dissemination of knowledge in complex communities of knowers as its subject matter, then its third party character is essentially stigmergic. In its most generic formulation, stigmergy is the phenomenon of indirect communication mediated by modifications of the environment. Extending this notion one might conceive of stigmergy as the extra-cranial analog of artificial neural networks or the extended mind. With its emphasis on *coordination*, it acts as the binding agent for the epistemic and the cognitive. Coordination is, as David Kirsh (2006, p. 250) puts it, "the glue of distributed cognition". This paper, therefore, recommends a stigmergic framework for social epistemology to account for the supposed tension between individual action, wants and beliefs and the social corpora: paradoxes associated with complexity and unintended consequences. A corollary to stigmergic epistemology is stigmergic cognition, again running on the idea that *modifiable* environmental considerations need to be factored into cognitive abilities. In this sense, we take the extended mind thesis to be essentially stigmergic in character.

This paper proceeds as follows. In Section 2, we set out the formal specifications of stigmergy. In Section 3, we illustrate the essentially stigmergic characteristics of social

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[1] The first "is" denotes a necessary property of knowledge, namely that knowledge acquisition involves the deployment of some cognitive apparatus. The second "is" refers on the other hand to a contingent fact: to cognize is to be culturally-bounded. (Thanks to Geoff Thomas for pressing us on this issue.)

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epistemology. In Section 4, we examine extended mind externalism as the preeminent species of stigmergic cognition. In Section 5 we illustrate how the particle swarm optimization (PSO) algorithm for the optimization of a function could be understood as a useful tool for different processes of social cognition, ranging from the learning of publicly available knowledge by an individual knower, to the evolution of scientific knowledge. In Section 6, we offer some concluding remarks.

2. Characterizing stigmergy

The term stigmergy was coined by zoologist Grassé (1959) whose research concerned cellular structure, protistology and animal sociology, the latter of particular fascination. Grassé sought to understand the mechanisms underlying the emergence, regulation, and control of collective activities in social insects. Specifically, Grassé's research sought to address the so-called "coordination paradox": that is, how does one reconcile behavior at the individual level (given that individuals are constrained by knowledge and material resources) with the global/societal level of the termite colony. At first sight, behavior at the individual level appeared to be chaotic, which of course is at odds with the visibly impressive structures that only a highly organized colony of termites could achieve. What Grassé discovered in the coordination and regulation of termite colonies, is the phenomenon of *indirect communication mediated by modifications of the environment* – stigmergy.

Until Grassé, the two competing theories on offer mirrored the individualism–holism debate in social philosophy, discussion of which is deferred to the next section. One theorized that novel properties appeared at the level of the society with its own nomological and causal system: the "whole" explains the behavior of the parts. The competing theory treats each individual insect as if it were operating completely alone. Any ascription of collective behavior or division of labor was deemed illusory. Biologist Etienne Rabaud laid the conceptual ground for Grassé by introducing two concepts:

1. Interaction.
2. Interattraction.

The former is the claim that individual behavior is essential to collective action. Creatures in close proximity to one another must have a reciprocal modifying behavior. The latter denotes the idea that creatures of the same species have a mutual attraction (for a detailed history of stigmergy in an entomological context, see Theraulaz & Bonabeau, 1999). Expanding upon Rabaud, Grassé took the view that sociality cannot merely be the result of interaction or interattraction as the individualist would have it. Collective behavior must also play a *reciprocal role in modifying* behavior, an insight he gleaned from his study of termite building behavior. Grassé observed that the coordination and regulation of building activities did not depend on the individual "agents" themselves but is informed by the structure of the nest. Pheromone traces left by others and modifications made by others have a cybernetic feedback. In other words, the environment acts a kind of distributed memory system.

Different theorists have proffered different varieties of stigmergy. Wilson (1975/2000, pp. 186–188) identifies two main variants:

- Sematectonic stigmergy.
- Sign-, cue-, or marker-based stigmergy.

Sematectonic stigmergy denotes communication via modification of a *physical* environment, an elementary example being the carving out of trails. One needs only to cast an eye around any public space, a park or a college quadrangle for instance, to see the grass being worn away, revealing a dirt pathway that is a well-traveled, unplanned and thus indicates an "unofficial" intimation of a shortcut to some salient destination.

Marker-based stigmergy denotes communication via a signaling mechanism (Engelbrecht, 2005; Kennedy, Eberhart, & Shi, 2001, p. 104). A standard example is the phenomenon of pheromones laid by social insects. Pheromone imbued trails increase the likelihood of other ants following the aforementioned trails. Unlike sematectonic stigmergy which is a response to an environmental *modification*, marker-based stigmergy *does not* make any direct contribution to a given task. This classification seems to be more or less coextensive with Holland and Melhuish's (1999) passive and active variant in that the former is informed by previous environmental modification (e.g. a vehicle obliged to follow the extant ruts in a muddied road); the latter, a positive intentional response to a given state of affairs. As Parunak (2005, p. 11) puts it sematectonic stigmergy is "the current state to the solution": by that we take him to mean that what confronts the agent at a given point is the accumulation of prior agent activity.

Theraulaz and Bonabeau (1999, pp. 104–105) talk of two classes of stigmergic mechanisms: *quantitative* and *qualitative*. With quantitative stigmergy, the stimulus-response comprises stimuli that do not differ qualitatively and only modify the *probability* of a response. So the stronger the pheromone trail, the larger the probability of a response. Qualitative stigmergy denotes the idea that individuals interact through, and respond to, qualitative stimuli, which in turn affects the behavior of those who follow – an ongoing iteration. To bring out this contrast better quantitative stigmergy would be the construction of pillars in termites' nests, the initial conditions being soil being infused with pheromone. In a qualitative stigmergic process, for example the construction of wasps' nests, a new cell is constructed to correspond with an existing cell (Camazine et al., 2003, p. 418).

In anticipation of extending the metaphor of stigmergy let's summarize the general features of a stigmergic system.