BENEFITS OF COLLECTIVE INTELLIGENCE: SWARM INTELLIGENT FORAGING

Sivave Mashingaidze *

Abstract

Wisdom of crowds; bees, colonies of ants, schools of fish, flocks of birds, and fireflies flashing synchronously are all examples of highly coordinated behaviors that emerge from collective, decentralized intelligence. This article is an ethnographic study of swarm intelligence foraging of swarms and the benefits derived from collective decision making. The author used using secondary data analysis to look at the benefits of swarm intelligence in decision making to achieve intended goals. Concepts like combined decision making and consensus were discussed and four principles of swarm intelligence were also discussed viz; coordination, cooperation, deliberation and collaboration. The research found out that collective decision making in swarms is the touchstone of achieving their goals. The research further recommended corporate to adopt collective intelligence for business sustainability.

Keywords: Collective Intelligence, Swarm Intelligent, Foraging, Ethnography

**Post-Doctoral Research Fellow, College of Economic and Management Sciences, Department of Business Management, University of South Africa*
Tel.: +2763 0095605
E-mail: mashis@unisa.ac.za

1. Introduction

As Levy observed in his early treatise on Collective Intelligence: "No one knows everything, everyone knows something (Lévy, & Bonomo, 1999). In most cases, a single insect is not able to find by itself an efficient solution to a colony problem, while the society to which it belongs finds "as a whole" a solution very easily (Camazine et al. 2001). Social insects work without supervision. In fact, their teamwork is largely self-organized, and coordination arises from the different interactions among individuals in the colony. Although these interactions might be

Primitive (one ant merely following the trail left by another, for instance), taken together they result in efficient solutions to difficult problems (such as ending the shortest route to a food source among myriad possible paths).The collective behavior that emerges from a group of social insects has been dubbed "swarm intelligence"(Bonabeau, & Meyer, 2001)

The remarkable collective action of these organisms such as swarming ants, schooling fish and flocking birds has long captivated the attention of artists, naturalists, philosophers and scientists. Despite a long history of scientific investigation, only now studies are beginning to decipher the relationship between individuals and group-level properties. This interdisciplinary effort is beginning to reveal the underlying principles of collective decision-making in animal groups, demonstrating how social interactions, individual state, environmental modification and processes of informational amplification and decay can all play a part in tuning adaptive response. It is little wonder that the behavior of animal groups, such as schools of fish, flocks of birds or swarms of insects has been associated with the concept of having a 'collective mind'. Grouping individuals often have to make rapid decisions about where to move or what behavior to perform, in uncertain and dangerous environments. Decision-making by individuals within such aggregates is so synchronized and intimately coordinated that it has previously been considered to require telepathic communication among group members or the synchronized response to commands given, somehow, by a leader.

This article thus reviews swarm intelligence in consensus and combined decision-making in bees and army ants and decipher the relationship between individuals and group level properties. The research question which this article tries to answer is: "Does business benefit from swarm intelligence foraging" The article is structured as follows:

Consensus decision making process and specific models, tools and methods of consensus decision making process, a decision-making process, consensus decision-making aims and some specific applications where consensus decision making has successful been implemented will be discussed. The last part of the article will look at four principles of swarm intelligence which are: coordination, cooperation, deliberation and collaboration. Swarm related experiments are hinted in the article. Whilst research has explored how groups choose among a number of actions, for example insects, fish, birds and mammals, there has been few a priori, theory-based expectations about the conditions under which a collective outperforms an expert, or vice versa. With the recent interest in swarm intelligence in behavioral and evolutionary ecology, a re-examination of the relationship between the uses of these alternate decision-making rules has been called for and this is the contribution of this article in the body of business knowledge.

2. Methodology: Ethnography and secondary data analysis

Ethnography is the art and science of describing a group or culture. The description may be of a small tribal group in an exotic land or a classroom in middle-class suburbia (Fetterman, 1998).

Ethnography literally means a portrait of a people and is a written description of a particular culture - the customs, beliefs, and behavior based on information collected through fieldwork and secondary data (Harris and Johnson, 2000). Secondary data is simply a reference to existing data, as compared to new data that are being collected, or have been recently collected. For all research approaches, secondary data analyses help in identifying gaps in what is known about particular research topics, and suggesting the specific methods that might be used to secure the most valid data related to the questions or topics of interest. Ethnography, similar to any other type of research usually begins with the researcher availing him or herself of the range of information that already exists on the topic or people being studied. One principle of ethnography is naturalism. This is the view that the aim of social research is to capture the character of naturally occurring human behavior. This is the reason that ethnographers carry out their research in "natural" settings, settings that exist independently of the research process, rather than in those set up specifically for the purposes of research. Another important implication of naturalism is that in studying natural settings the researcher should seek to minimize her or his effects on the behavior of the people being studied. The aim of this is to increase the chances that what is discovered in the setting will be generalizable to other similar settings that have not been researched. Finally, the notion of naturalism implies that social events and processes must be explained in terms of their relationship to the context in which they occur (Hammersley, 1990).

3. Intelligence

There is almost unmanageable number of interpretations and meanings from different time periods and subject areas, interpretations which are considerably divergent, sometimes to the point of controversy. A few selected definitions and uses of “intelligence” from Antiquity to present day are noted below:

- Intelligence is what intelligence tests measure [Boring 1923].
- The term intelligence is understood to mean adaptive behavior as a means of conserving life, or more specifically the species [Cruse, 2003].
- Intelligence is a biophysical potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture [Gardner 2002].
- Intellect relieves human beings of the pressure to physically adapt to the environment and instead enables them to adapt the environment to their own needs [Turner, Müller, & Dulewicz, 2009].

Based on the definition of Howard Gardner we derive the following definition for intelligence: “Intelligence is the degree of a living thing’s ability to overcome challenges through the processing of information.” In this definition intelligence is not regarded as ability, but rather a measure of ability. This also permits creatures such as ants, bees, which are comparatively less intelligent, to be attributed with a degree of intelligence.

3.1 Swarm Intelligence: Basic concepts and related works

Swarm intelligence is the emergent collective intelligence of groups of simple agents. Each agent can interact with its local environment and other agents, but acts independently from all other agents. Some authors indicate that these agents are autonomic agents and some others believe that the agents are not necessarily autonomic. Word swarm describes a certain family of social processing integrated by simpler units. It typically refers to a cluster of things such as insects, animals or artificial agents, in which individuals move in apparently random directions, but the group stays together as a whole. Using emergent behavior, simple processes and self-organization, swarm intelligence can lead to complex results. Marvel ventilated termite mounds, ant shortest path routing, optimized labor allocation in bee colonies, swimming fish flocks and complex human swarms are some instances of natural swarm abilities.

Swarms are characterized by the seven unique properties:

- wholeness
- intensive interactive dynamics
- flexibility

- high level of potential for formation of transient dynamic patterns and
- accomplishment of coherent actions
- alertness
- receptiveness
- criticality (edge-of-chaos behavior).

These properties endow the swarm with an exceptional ability for survival, which is reinforced by equal participation of all swarm members. In a swarm of bees, for example, the natural emergence of differentiation between drones, queens, and workers exists in harmony with the bees' drive towards supporting the swarm's continuity, its ongoing adaptation and fitness - qualities that crucially depend on the contribution of each and every single bee.

Team Intelligence is the degree of ability of two or more living things to overcome challenges through the aggregation of individually processed information, whereby the actors don't follow completely identical rules of how to participate in the team. (Andreas and Miller 2014).

3.1.2 How social insects make group decisions?

Conradt and Roper (2005) proposed a useful conceptual distinction to classify animal group decision-making which called, combined and consensus decisions.

3.1.3 Combined decision-making

It refers to cases where animals decide individually, without requiring a consensus but in a manner that is somehow dependent on the behavior of other group members; the aggregate results of these individual decisions critically affect the group as a whole. Many foraging decisions fall into this category, where foragers seek resources (e.g., nectar, prey) individually but under social influence (for example, using social-frequency information) from other foragers (Conradt and Roper 2005)

3.1.4 Consensus decision making,

It concerns cases in which group members make decisions together with the requirement of reaching a consensus that is all members abiding by the decision outcome. Moving decisions, including decisions about where and when to migrate to a new nest site, fall into this category. Some foraging decisions (e.g., cooperative hunting by both humans and non-humans) are also in this category. In the following succeeding sections, the article will review group decision-making by ants and honeybees respectively, according to these categories (Conradt,& Roper, 2005).

3.1.5 Army Ant Colony

According to Dorigo, (2006), ants communicate with each other using pheromones. While searching in its environment, a worker ant will often pause briefly to deposit a small amount of pheromone along its route. Others are attracted to these pheromone markings, and will often reinforce them while following the trail. This seemingly simple mechanism provides a foundation for a complex array of coordinated behaviors and patterns, including the formation of trails to food resources and new nest sites, and optimization of these behaviors according to adaptive principles (Hölldobler, 2005).

3.1.6 Combined decisions in Ant Colonies

Goss, Aron, Deneubourg & Pasteels (1989) did an experiment to examine how ants, which have only a limited individual capacity for orientation, were able to locate food resources efficiently as collectives. In one experiment they placed a bridge between a nest of ants (Iridomyrmex humilis) and a food source. The bridge had a skewed figure-8 shape. Starting from the nest end, it split into two branches of different lengths at two different points, which eventually merged to the same destination where the food was placed. A forager/searcher going in either direction (leaving the nest or leaving the food) had to choose between two paths at 2 choice points, which yielded four routes in total. Results showed that, 5-10 minutes after placement of the bridge, explorers crossed it and discovered the food. A few minutes later, the shortest path between the nest and the food source was followed by a large majority of the ants. The ants solved the route-finding problem correctly as a collective (Goss, Aron, Deneubourg & Pasteels 1989). How this was made possible!

This occurred because ants traveling the shorter path returned home faster and thus reinforced the pheromone markings on the path more frequently (that is a path whose length is half of the other's is marked twice while an ant travels to and from the food source, as compared to the other path that could be marked only once in the same time period), and because others were nonlinearly attracted to the higher pheromone concentration (Kuenen, & Baker, 1982.

In another experiment, Beckers, Deneurourg and Goss (1993) presented ants (Lasius niger) with two food sources of different quality, which were connected to the nest by a Y-shaped bridge. One end of the bridge always had a 1 M (mol/L) sugar source, while the other end had either half (0.5 M). Results showed that proportions of the ants visiting the richer source increased rapidly as the difference in concentration between the two sources increased, with 86% of the ants visiting the 1 M source over the 0.5 M source. This occurred because each ant laid pheromone trail markings in proportion to the concentration of sugar solution found (the richer the source, the more pheromone), and because others were nonlinearly drawn to stronger pheromone markings between the two ends.

3.1.7 Consensus decisions in Ant Colonies

According to Conradt, Roper, (2005) and Sumpter, (2010), nest migration of ants requires not only individual search behaviors as we have seen above, but also some mechanisms to aggregate individual judgments into a consensus. In gregarious species such as ants, all members must abide by the consensus outcome whether or not they contributed to it, in order to maintain group cohesion against predation and other risks. Quorum rules are usually used in these situations to yield the group consensus.

Franks, Pratt, Mallon, Britton, & Sumpter, (2003) conducted a series of experiments to examine how ants (Leptothorax albipennis) choose a new nest from among several options, which had different values on three attribute dimensions (darkness, height, and width). Results showed that an ant colony whose nest had been damaged was able to aggregate the attribute information coherently, choosing the best nest site in terms of overall quality from among as many as five options. The colony also completed migration (that is all individuals transferred) to the new nest site within a couple of hours. Using an agent-based computer simulation, (Franks, Pratt, Mallon, Britton, & Sumpter, 2002) showed that such collective intelligence in a colony's migration can be understood by the following process model. The model assumes that migration proceeds by four different phases, in which ants gradually develop commitment to a particular nest site.

When nest damage is initially detected, a subset of workers (about 30% of the colony) starts an exploration phase, individually searching for candidate sites. Upon finding a candidate site, an individual ant enters an examination phase, carrying out an independent quality evaluation of the site, whose duration is inversely proportional to the site's quality (less time for higher-quality sites). Once the individual has accepted the site in terms of quality, she enters a canvassing phase, returning to the old nest to recruit another ant to the new site (via "tandem-run")(Franks, Pratt, Mallon, Britton, & Sumpter, 2002). Each of the recruited ants then makes her own independent examinations of the new nest, proceeding to further tandem-run canvassing if warranted. Because ants take less time to accept higher-quality sites, overall recruitment is faster to such sites. Finally, once the population in the new nest exceeds some "quorum threshold," a recruiting ant enters a committed phase. The recruiters stop the relatively slow tandem-runs, and accelerate the migration process by carrying passive nest-mates and brood to the new nest site (Grüte, Czaczkes, & Ratnieks, 2011). This quorum threshold marks a key feature of ants' migration as a consensus (and not combined) decision. Ant foragers have been shown to memorise both the locations of food sources and times at which they are profitable (Grüte., Czaczkes, & Ratnieks, 2011). Similarly, ant scouts can not only remember locations of new nest sites in order to immediately recruit to them (Mallon 2001), but also remember previously found sites for later avoidance.

3.2 Honeybees

According to Seeley, (2009) honeybees communicate with each other about movement decisions primarily through a "waggle dance" with a figure-8 pattern. Waggle dances are performed by foragers that have located food resources (nectar, pollen), water resources, or new nest sites. The direction and duration of the waggle dances are known to be related to the direction and distance from the hive to the resource. Decision-making by individuals within such aggregates is so synchronized and intimately coordinated that it has previously been considered to require telepathic communication among group members or the synchronized response to commands given, somehow, by a leader.

3.3 Combined decisions in honey bees

Seeley, & Buhrman, (1999) conducted a series of field experiments to test how efficiently a colony of honey bees could exploit nectar sources. These researchers placed two feeders (one feeder contained more concentrated sugar than the other) in opposite directions (with each being 400 meters away) from the hive, and altered the location of the richer feeder after 4 hours. The bees were able to track this change, and consistently focused their foraging efforts as a colony on the more profitable feeder. Seeley and colleagues then examined how the colony-level ability emerged from the behavior of individual bees through a series of ingenious manipulations (Seeley, & Buhrman, 1999).

Results showed that the honeybees finely adjusted several components of their foraging behavior in accordance with nectar source profitability. When the quality was higher than some threshold, the bees foraged more quickly and danced more vigorously, thereby recruiting other bees to exploit the richer source (Seeley, & Buhrman, 1999). Furthermore, virtually all foragers visited only one of the two feeders during their foraging. This means that the bees achieved high colony-level performance using only individual-level calculations of absolute profitability rather than relative comparison of multiple sources. In other words, this process is based on a decentralized control, whereby a coherent colony-level response to different food sources emerges from local interactions without overall consensus being explicitly sought (Seeley, & Buhrman, 1999).

3.4 Consensus decisions in honey bees

In late spring to early summer, as a large hive outgrows its nest, a colony of honey bees often divides itself. The queen leaves with about 2/3 of the worker bees to create a new colony, and a daughter queen stays in the old nest with the rest of the worker bees (Seeley, 2010). The swarm leaving the colony must find a new home in a short time, which is critical to their survival. The departing swarm, which is composed of 10,000 or so bees, typically clusters on a tree branch, while several hundred scout bees search the neighborhood for a new home. These scout bees fly out to inspect potential nest sites, and, upon returning to the colony, perform waggle dances to advertise any good sites they have discovered (Seeley, 2010).

In an experiment, Seeley and Buhrman (2001) presented honeybees with an array of five nest boxes, only one of which was a high-quality nest site while the other four were of medium-quality. The honeybee swarms chose the best nest site 80% of the time. As in the foraging case, this swarm-level performance in nest search was modulated by a scout bee’s adjustment of waggle dances in accordance with nest site quality: the better the site, the stronger the dance. Other scout bees that have not flown out yet, as well as those that have stopped dancing, observed these dances and decided where to visit. In these decisions, the bees were more likely to visit and inspect the sites which have been advertised strongly by many predecessors. This process constitutes a positive feedback loop, yielding the swarm intelligence displayed in locating the best nest site (Seeley and Buhrman 2001).

Different from the foraging case, however, the scout bees must terminate the search phase at some point and mobilize the entire swarm to the new nest. Seeley and Visscher (2003) examined how such consensus decisions, which all members must abide by, were made. Results from a series of experiments showed that the honeybees used a quorum rule, where they began preparations for liftoff as soon as enough of the scout bees (not necessarily all of them, nor in fact any of the non-scout bees) have approved of one of the potential nest sites. When the quorum was reached, the scout bees used special wing-beat signals, known as “piping,” to alert other non-scout bees in the swarm to warm up their muscles in preparation for the entire swarm to lift off and fly to the new nest (Visscher & Seeley, 2007)

3.5 Team Intelligence lessons learnt from group decision making by social insects

The article selectively reviewed some of the recent findings on group decision making by ants and honeybees, focusing on proximate mechanisms by which these animals achieve high-level performances as collectives for a comprehensive expert review (Detrain and Deneubourg, 2008).

3.6 Significant mechanisms underlying swarm intelligence

Taken together, the combined and consensus decisions of ants and honeybees when foraging for food or when migrating to a new nest site, have several key elements in common to yield their highly impressive group-level performances. The key factors include positive feedback along with nonlinear responses to social frequency information (for example trail markings by pheromones; the number of bees engaging in waggle dances). In the foraging case the process is started by one forager that finds a food source first, which is followed by more and more foragers over time (positive feedback) (Conradt & Roper, 2005). As more foragers are recruited, the rate of recruitment accelerates further, because foragers react to the social-frequency information in a nonlinear manner (for example, more accentuated than proportional responses). Small initial differences in social frequency between options are thus amplified, so that the option favored by the greatest frequency is eventually taken by most foragers in the colony (Conradt & Roper, 2005). In the case of nest migration where mobilization of the entire group is critical (consensus decisions: Conradt & Roper, 2005), this process is further accelerated and cemented by a quorum rule. The probability of performing an action increases sharply when a certain social frequency, or quorum, is reached. Such a quorum threshold marks a critical point whereby the entire colony shifts from an exploration phase to a commitment/action phase (Sumpter, & Pratt, 2009).

3.7 Corresponding mechanisms in human group decision making

These social mechanisms (ants and bees) have remarkable similarities that can be adopted by human group decision making (Kameda, Wisdom, Toyokawa, & Inukai, 2012). As in the animal cases the article have reviewed that, this process (combined and consensus decision making) often causes positive feedback loops in human groups as well, ranging from spread of happiness (Fowler & Christakis, 2008) and business performance (Christakis & Fowler, 2007). When official consensus is required, human groups at all levels often should rely on some aggregation rule not top-down mechanism where shop flow employees are recipients of the policy and are not even consulted to contribute. This is functionally equivalent to the “quorum rule” in animal consensus-decisions (Conradt & Roper, 2005).

4. The intelligence of crowds, the Condorcet Jury Theorem

Davis, (1973); Kerr, Stasser & Davis, (1979); and Kameda et al., (2003) propounded that the majority/plurality aggregation in human as well as animal group decision-making, as observed by the article above, removes any dominant tendency in individual responses at the collective level. When the number of options in a choice set is two (for example to migrate or not), this process can be described by the Condorcet Jury Theorem below, formalized by the Marquis de Condorcet, a French social philosopher of the 18th century (Austen-Smith, & Banks, 1996).

To illustrate the above, suppose that a group with 2m+1 members works on some problem with an objectively true (but unknown) solution. The choice set is thus classifiable into binary behavioral categories, the one correct (a) option versus the other incorrect (b) options. Assuming that each individual makes a decision independently from each other, the probability, PG, that the group reaches the correct choice by the majority rule is given by:

$$\mathrm{P(G)} = \sum_{\mathrm{n=m+1}}^{\mathrm{2m+1}} \binom{\mathrm{2m+1}}{\mathrm{n}} \mathrm{pn(1-p)2m+1}$$

where p is the (average) probability that each individual endorses the correct option personally. And if individual accuracy (p) is greater than 0.5, the group accuracy under the majority rule is enhanced above p (i.e., PG > p > .5), a phenomenon known as “the wisdom of crowds” (Surowiecki, 2004).

Such a group-level improvement becomes even larger (i.e., PG approaches nearly 100% accuracy) with an increase in group size (Kerr, & Tindale, 2004). When group aggregation is done by averaging (e.g., Kameda et al 2012), a similar group-level improvement is achieved by the law of large numbers in statistics (Galton, 1907).

In either case, even if each group member is not very competent (“many wrongs”: Simons, 2004), these simple aggregation mechanisms (majority rule, averaging) can cancel out individual errors and thus yield more accurate decisions in groups as compared to isolated individuals (Kämmer, Gaissmaier, Reimer, & Schermuly, 2014).

Research by Detrain & Deneubourg, (2002) denotes that ants and honeybees seem to be able to solve these potential problems in collective decision making actions. For example, as was stated above, ants lay pheromone trail markings in proportion to the concentration of sugar solution found (the richer the source, the more pheromone: Beckers et al., 1993); for prey scavenging, the strength of an individual’s recruitment pheromone trail is inversely proportional to ability to move the prey. Honeybees also adjust finely several components of their foraging behavior in accordance with nectar source profitability: when the quality is higher than some individual thresholds, the bees forage more quickly and dance more vigorously (Seeley et al., 1991). These fine-tuned (and genetically acquired) mechanisms seem to assure that ant/honeybee foragers have at least moderate individual accuracies (for example p > .5) in most natural cases (though of course sudden changes in their adaptive environments can work against such fine-tuned mechanisms).

Human beings have an added advantage with their unique language faculty; such flexible cognitive capacity allows them to be far better individual learners (and problem solvers) in much broader contexts than any other species on earth (Kokis, Macpherson, Toplak, West, & Stanovich, 2002)) if they can emulate the swarm intelligence system. The majoritarian decision-making can beat other decision mechanisms in a broad parametric range under uncertainty. Kameda et al. (2011) called such superb performances of majoritarian group decision-making “democracy under uncertainty. From the preceding description of self-organizing processes of swarms the following principles are discussed: coordination, cooperation, deliberation and collaboration.

4.1 Coordination

Coordination is the appropriate organization in space and time of the tasks required to solve a specific problem. This function leads to specific spatio-temporal distributions of individuals, of their activities and/or of the results of their activities in order to reach a given goal (Garnier, Gautrais, & Theraulaz, 2007). Coordination is also involved in the exploitation of food sources by pheromone trail laying ants. They build trail networks that spatially organize their foraging behavior between their nest and one or more food sources (Garnier, Gautrais, & Theraulaz, 2007)

4.2 Cooperation

Cooperation occurs when individuals achieve together a task that could not be done by a single one. The individuals must combine their efforts in order to successfully solve a problem that goes beyond their individual abilities. Cooperation is obvious in large prey retrieval, when a single individual is too weak to move a food item. Many cases of cooperative transport of prey were reported for several ant species such as weaver ants, army ants, and wood ants *(*Boström, & Bonsdorff, 1997). It was reported that ants engaged in the cooperative transport of a prey can hold at least ten times more weight than did solitary transporters ants *(*Boström, & Bonsdorff, 1997).

4.3 Deliberation

Deliberation refers to mechanisms that occur when a colony faces several opportunities. These mechanisms result in a collective choice for at least one of the opportunities. For instance, honeybees select the more productive floral parcels thanks to the recruitment of unemployed workers by the waggle dance performed by foragers returning from a food source (Seeley et al. 1991). When ants of the species have discovered several food sources with different qualities or richness, or several paths that lead to a food source, they generally select only one of the different opportunities. In this case, the deliberation is driven by the competition between the chemical trails leading to each opportunity. In most cases, ants will forage at the richer food source and travel along the shorter path toward the food source (Dorigo, & Gambardella, 1997)

4.4 Collaboration

Collaboration means that different activities are performed simultaneously by groups of specialized individuals, for instance foraging for prey or tending brood inside the nest (Ingram, Oefne, & Gordon, 2005). This specialization can rely on a pure behavioral differentiation as well as on a morphological one and be influenced by the age of the individuals. The most conspicuous expression of such division of labor is the existence of castes. For instance, in leaf cutter ants workers may belong to four different castes and their size is closely linked to the tasks they are performing (Hölldobler and Wilson 1990). Only the workers whose head size is larger than 1.6 millimeters are able to cut the leaves that are used to grow a mushroom that is the main food source of these colonies. On the contrary, only the tiny workers whose head size is about 0.5 millimeters are able to take charge of the cultivation of the mushroom. Differently, all workers look alike but they do not work to the same extent and they do not perform the same kind of tasks. Some of the workers are foragers and take most of the burden of going out of the colony in search of food and building materials. Others specialize in staying and working at the nest. Among these, some are more aggressive towards their nest mates and they are called fighters. The other wasps staying at home are called sitters and spend most of the time just sitting and grooming themselves (Gadagkar and Joshi 1983, 1984).

5. Corporate Lessons from swarm intelligence

Corporates are not used to solving decentralized problems in a decentralized way. They typically think of a leader as someone who can influence workers and workers are willing to follow because they believe in the cause or the vision (Trewavas, 2014). With decentralization there is no leader and members collectively choose to act in a manner that is best for the whole. For example, consider the way Google uses decentralization (swarm intelligence) to find what you are looking for. When you type in a search query, Google surveys Web pages on its index servers to identify the most relevant ones. What is most relevant? Google uses the swarm intelligence of those using the Web to determine a page's relevancy. This is swarm intelligence—no manager, no leader (Doyle, 2012). Such thoughts underline an important truth about swarm intelligence. Crowds tend to be wise only if individual members act responsibly and make their own decisions. A group will not be smart if its members imitate one another, slavishly follow fads, or wait for someone to tell them what to do. When a group is being intelligent, whether it is a colony of ants or a group of attorneys, it relies on its members to do their own part. First, any collective requires individuals who appreciate, understand and have the skills and abilities to function in their independent roles and responsibilities. Although all the individuals in the group make the collective, this first step is not an exercise for the collective; this is for each individual. The analogy is to the single ant, bird, fish or honeybee where each must have the skill and ability to perform the job.

Second, each individual acts responsibly and adopts key group values called values of a peer-based organisation.

- Openness—everyone shares equally in information.
- Transparency—everyone shares equally in decision-making.
- Alignment—everyone shares equally in leadership roles and responsibilities.
- Competence—everyone shares equally in the development of peer competencies

Finally, the role of a manager and of a leader is to consult, facilitate and serve each individual in the workgroup. This means to never be a traditional boss, never be one to hoard information, and never be one to make all the decisions.

6. Findings and discussion

The research found out that the collective decisions in ants rely on self-organization that appears to be a major component of a wide range of collective behaviors in social insects, from the thermoregulation of bee swarms to the construction of nests in ants and termites (Bonabeau et al. 1997; Camazine et al. 2001). Taken together, the combined and consensus decisions of ants and honeybees when foraging for food or when migrating to a new nest site, have several key elements in common to yield their highly impressive group-level performances. This self-organization relies on four basic ingredients:

- The first component is a positive feedback that results from the execution of simple behavioral "rules of thumb" that promote the creation of structures. For instance, trail recruitment to a food source is a kind of positive feedback which creates the conditions for the emergence of a trail network at the global level.

- Then we have a negative feedback that counterbalances positive feedback and that leads to the stabilization of the collective pattern. In the example of ant foraging, negative feedback may have several origins. It may result from the limited number of available foragers, the food source exhaustion, and the evaporation of pheromone or a competition between paths to attract foragers
- Self-organization also relies on the amplification of fluctuations by positive feedbacks. Social insects are well known to perform actions that can be described as stochastic (non deterministic). Such random fluctuations are the seeds from which structures nucleate and grow. Moreover, randomness is often crucial, because it enables the colony to discover new solutions. For instance, lost foragers can find new, unexploited food sources, and then recruit nest mates to these food sources.
- Finally, self-organization requires multiple direct or stigmergic (indirect coordination) interactions among individuals to produce apparently deterministic outcomes and the appearance of large and enduring structures.

7. Conclusion and recommendation

Business performance in the knowledge economy is no longer just about producing and interpreting facts, but also about mobilizing the tacit knowledge and collective intelligence of its stakeholders. For this to happen, business needs to build a learning capacity within its organization. Learning to acquire tacit knowledge and experience must be a permanently ongoing process. As exemplified in the previous subsections, the organization of collective behaviors in social insects can be understood as the combination of the four coordination, cooperation, deliberation and collaboration functions. Each of these functions emerges at the collective level from the unceasing interactions between the swarms. They support the information processing abilities of the colony according to two main axes:

1. Coordination and collaboration shape the spatial, temporal and social structures that result from the colony's work. The coordination function regulates the spatio-temporal density of individuals while the collaboration function regulates the allocation of their activities.
2. Cooperation and deliberation provide tools for the colony to face the environmental challenges. The deliberation function represents the mechanisms that support the decisions of the colony, while the cooperation function represents the mechanisms that overstep the limitations of the individuals.

Together, the four functions of organization produce solutions to the colony problems and may give the impression that the colony as a whole plans its work to achieve its objectives. Swarms of bees, colonies of ants, schools of fish, flocks of birds, and fireflies flashing synchronously are all examples of highly coordinated behaviors that emerge from collective, decentralized intelligence. Local interactions among a multitude of agents or "swarmettes" lead to a variety of dynamic patterns that may seem like choreographed movements of a meta-organism. Social insects work without supervision. In fact, their teamwork is largely self-organized, and coordination arises from the different interactions among individuals in the colony. Although these interactions might be Primitive (one ant merely following the trail left by another; for instance), taken together they result in efficient solutions to difficult problems (such as ending the shortest route to a food source among myriad possible paths).

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