Collective Cognition: *An enactive account, via concepts of sympoiesis and super-organisms*

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Abstract. This paper situates itself within the enactive paradigm in cognitive science, and explores whether this new account of cognition can be extended to groups of multicellular organisms. In particular, the paper argues that by incorporating the notion of *sympoiesis* into the *enactive theory of mind*, and introducing the concept of *strong organizational closure*, certain highly autonomous groups of multicellular organisms, such as insect "super-organisms", can be understood to enact a kind of group-level sense-making via *sensorimotor contingency theory*, and thus can be understood to enact a kind of collective cognition. The paper proposes the notion of *collective cognition* in part as a new heuristic device for cognitive science – a concept that may help us to better understand both the emergent behaviours of certain groups of living organisms, as well as the concept of embodied cognition more generally, even in the case of single organisms. However, given the general difficulty of directly proving that another organism is cognizing, and the added difficulty that arises when the organism's structure is broadly distributed, the paper chooses to suspend judgement as to whether or not super-organisms *actually* are collectively cognitive.

Introduction

In the 1990's a theory of mind was developed that attempted to reconceive the mind/body problem, so as to explain precisely how it was that a material structure might give rise to cognition (Varela, Thompson, Roche, 1992). This theory, called the *enactive theory of mind*, was unlike traditional approaches to cognitive science, in that it proposed a deep continuity between mind, living activity, and thence life (Thompson, 2007), thereby avoiding the mind/body problem altogether by equating processes of cognition with life's basic pattern of organization. According to the *enactive approach*, all living systems *enact* or "bring forth" their own particular worlds of meaning through their living activities within a *niche*, and it is this "bringing forth" of a world that constitutes cognition (Stewart, Gapenne, Di Paolo, 2010, pg. 3). However, as all living systems are thought to operate within a niche by virtue of their self-producing, or *autopoietic*, patterns of organization, and because the maintenance of *autopoiesis* also requires that living systems be *adaptive*, both autopoiesis and adaptivity are understood to be jointly necessary and sufficient for cognition (Thompson, 2010, pg. 148). The enactive approach therefore considers *all* living systems to be cognitive systems, because all living systems are understood to satisfy these two criteria (Maturana, 1970; Varela, Maturana, 1973). In the words of Humberto Maturana, "*living systems are cognitive systems, and living as a process is a process of cognition*" (Maturana, 1970, pg. 13, emphasis in original text).

The present paper situates itself within the enactive paradigm (Varela, Thompson, Roche, 1992; Stewart, Gapenne, Di Paolo, 2010), and explores whether this new account of cognition can be extended to groups of multi-cellular organisms. In particular, the paper focuses on colonies of eusocial insects that some scientists themselves conceptualize as "super-organisms" (Hölldobler and Wilson, 2009). It shows how the concept of *sympoiesis* (Dempster, 2000), if

combined with the notion of *strong organizational closure*, lets us, via *sensorimotor contingency theory* (Noë, 2004) understand these systems as enacting a kind of sense-making at the group-level, and thus as enacting a form of collective cognition. Specifically, the paper suggests that as the individual organisms that compose a super-organism become increasingly sensitive to higher-level sensorimotor contingencies, they may begin to develop higher-level sensorimotor know-how, thus allowing them to collectively-enact higher-level behaviours, and thereby open up a higher-level niche, which, under the enactive theory of mind, would make them collectively cognitive.

However, directly proving that another organism is cognizing, has cognitive experience, or has a perceptual world (or *Umwelt*), and so on, remains a challenge for cognitive science in general, and this problem is perhaps even more difficult in cases where the organism's structure is broadly distributed, as with super-organisms. Thus, the question as to whether or not super-organisms are *actually* collectively cognitive is a subject on which the paper chooses to remains silent. The point of the paper is rather to show that if we adopt an enactive theory of cognition, and extend it via concepts of sympoiesis and strong organizational closure, we *can* think that super-organisms are cognitive systems. That is, this is an open question, just as much as whether or not a dog or bacterium is a cognitive system, and so further investigation is required. Indeed, the paper is proposing the concept of *collective cognition* in part as a new heuristic device for cognitive science – a concept that may help us to better understand both the emergent behaviours of certain groups of organisms, as well as the notion of embodied cognition more generally – even in the case of single organisms.

Part 1: The Enactive Paradigm

Enaction has been described as a new paradigm in cognitive science (Stewart, Gapenne, Di Paolo, 2010). This new paradigm is centered on the biological theory of *autopoiesis*, which proposes that all living systems are essentially defined by a self-producing – or *autopoietic* – pattern of organization (Maturana, Varela, 1973). According to the theory of autopoiesis, all living systems are essentially characterized by a tight interlocking or bootstrapping of components, and the relations between these components is what produces their structures; however, at the same time, the structures of living systems also help to reciprocally maintain those very same networks of relations that produce the components of which they are built. In other words, living systems are understood to be self-produced because they maintain their own internal reaction networks via their external structures. For example, a single celled organism is produced through a metabolic reaction network, however the structure of the organism's cell wall, once produced, also helps to maintain that very same metabolic reaction network that gave rise to it. The concept of autopoiesis is meant to capture this type of underlying circularity, and, for the enactive approach, it is this basic self-producing pattern of organization that gives rise to both life and mind (Thompson, 2010).

Let us therefore begin by defining an autopoietic system. According to Francisco Varela and Humberto Maturana, the two biologists who proposed the concept, an autopoietic system can be defined as:

> *A machine organized (defined as a unity) as a network of processes of production, transformation, and destruction of components that produces the components which: (i) through their interactions and transformations*

> *regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it as a concrete unity in the space in which they exist by specifying the topological domain of its realization as such a network*. (Varela, Maturana, 1973, pg. 78, emphasis in original text)

As this definition suggests, autopoietic systems are characterized by a type of reciprocal causality that causes them to emerge as bounded and self-defined entities within their environments. Importantly, such systems are also understood to specify their own domains of operation, and it is in this way that the autopoietic pattern of organization is thought to constitute a *niche*.

A niche is considered to be the necessary counterpart of an autopoietic system because, by realizing its own network of relations, an autopoietic system simultaneously specifies the domain in which it operates. In other words, by virtue of its very pattern of organization the autopoietic system *distinguishes* between its own processes and those of an external environment and, in doing so, generates the very first instance of meaning – the primordial distinction between self and other. Thus, by determining its own processes, the autopoietic system necessarily emerges within a meaningful environment, establishing itself as a living system within a niche. In the words of John Stewart, "the emergence of a dissipative structure brings about the differentiation between two inseparable entities: the 'organism' on the one hand, its 'ecological niche' on the other...they exist, as such, only in relation to each other" (Stewart, 2010, pg. 2). For this reason, the concept of autopoiesis suggests that neither the living system nor its niche is ontologically primary, but rather the two are both co-emergent and co-constitutive.

By emphasizing this inherent inseparability of organism and niche, as well as the

important relationship between the niche and cognition, the theory of autopoiesis challenges traditional brain-centered approaches to the mind. For example, rather than conceiving of cognition as a process that occurs strictly in the brain, the concept of autopoiesis emphasizes the way in which a living system's total autopoietic pattern of organization establishes meaning in order to maintain its own viability. As Humberto Maturana explains, "a cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself, and the process of cognition is the actual (inductive) acting or behaving in this domain" (Maturana, 1970, pg. 13). The enactive approach takes this new understanding of cognition as its basis, and emphasizes the way in which meaning is *enacted* by living systems as they move through those meaningful environments in which they are embedded (Varela, Thompson, Roche, 1992; Thompson, 2007). In this way, the enactive approach has begun to blur traditional boundaries between brain, body, and world (Thompson, 2007), thus paving the way for new, more distributed concepts of mind – concepts like *participatory sense-making* (De Jaegher, Di Paolo, 2007), *group-mind* (Theiner, 2008), and, as I will argue, *collective cognition*.

Perception

The enactive approach to cognitive science has also begun to shape contemporary theories of perception (Noë, 2004). For example, under the enactive approach, traditional theories of perception, in which incoming sense data is thought to be directly responsible for perceptual experience, should be replaced by theories in which perceptual experience is understood to emerge through the inherently circular dynamic of the organism. According to the enactive approach, for example, it is the modulation of an organism's autopoietic organization, as a result of environmental perturbations, that generates its meaningful perceptual experience, and not

simply the direct reception of sense data itself. For this reason, the colour red should not be thought of as a quality of light, for instance, but should instead be thought of as a quality of perceptual experience that emerges when a spectrum of photons modulates a living system in such a way that the impression of red is experienced. In other words, for the enactive approach, visual experience is not the *direct* result of photons hitting the retina, exciting the optical nerves, and signalling the visual cortex, etc., but is rather an *indirect* result of these processes, emerging through the organism's total understanding of its bodily state, which also includes other, traditionally non-visual processes. (Note that this "understanding" can be and often is implicit, unconscious, habitual, etc.—manifest as "know-how" vs. "knowing that.") For example, according to *sensorimotor contingency theory* (Noë, 2004), pre-reflective understanding of the contingent relationships that exist between one's sensations and movements can have a significant affect on one's perceptual experience. In the words of Alva Noë, "it is this knowledge of the way sensory stimulation varies as a function of movement that is the basis of our ability to have world-presenting sensory experience (Noë, 2004, pg. 117). This kind of pre-reflective understanding has been called *sensorimotor know-how* (Noë, 2004).

At this point it may be helpful to briefly mention the writings of philosopher Maurice Merleau-Ponty (Merleau-Ponty, 1962; 1965), whose phenomenological investigations were in many ways a foreshadowing of the enactive theory of mind. Throughout his work, Merleau-Ponty consistently emphasized the important relationship between the dynamic structure of the lived body and its emerging world of experience, developing concepts like the *body schema*. As Merleau-Ponty explains:

> To have senses, sight for example, is to possess that general apparatus, that cast of possible, visual relations with the help of which we are able to take up any given

> visual grouping. To have a body is to possess a universal setting, a schema of all types of perceptual unfolding and of all those inter-sensory correspondences which lie beyond the segment of the world which we are actually perceiving. A thing is, therefore, not actually *given* in perception, it is internally taken up by us, reconstituted and experienced by us in so far as it is bound up with a world, the basic structures of which we carry with us, and of which it is merely one of many possible concrete forms. (Merleau-Ponty, 1962, pg. 380)

Thus, the notion of the body-schema may be a helpful concept to bear in mind when it comes time to discuss the higher-level structures of super-organisms, and especially when considering the possibilities of higher-level sense-making and higher-level sensorimotor know-how. It may be helpful, for example, to consider the possibility of a higher-level body-schema, or a *collective body-schema*, when thinking about the possibility of collective cognition.

Metabolism

In order to better understand the relationship between living systems and processes of cognition it may also be helpful to consider the concept of metabolism. To begin with, all living systems are thermodynamically open, and must actively compensate for the breakdown of their structures by using energy to take in new material from the external environment, and then transforming it into usable components. In other words, all living systems must metabolize. What this basic requirement of living systems illustrates, as philosopher Hans Jonas has pointed out, is that what we actually identify as a living system is not that transient collection of material components that makes up the system, but rather the underlying *form* of the system itself (Jonas, 1966, pg. 80). In

other words, because the components of living systems are continuously and *essentially* in a state of flux, to be a living system is actually to be certain type of formal organization – a pattern – and not any particular arrangement of numerically identifiable molecules. This idea is of course quite consonant with the notion of autopoiesis, which, as we have already seen, suggests that all living systems are essentially defined by a self-producing pattern of organization.

Furthermore, Jonas, anticipating the concept of autopoiesis, also proposed that the emergence of a living system implies the emergence of a *self-identity*, as it is a living system's self-identity that compels it to hold together despite thermodynamic openness (Jonas, 1966, pg. 82). Moreover, according to Jonas, it is this very same openness to the world that compels a living system to *transcend* its bodily state, in search of that new material that will allow it to maintain its organization (Jonas, 1966, pg. 84). Thus, for Jonas, living systems are characterized by a kind of 'needful freedom'. As Jonas explains:

> In order to change matter, the living form must have matter at its disposal, and it finds it outside itself, in the foreign 'world'. Thereby life is turned outward and toward the world in a peculiar relatedness of dependence and possibility. Its want goes out to where its means of satisfaction lie; its self-concern, active in the acquisition of new matter, is essential openness for the encounter of outer being. Thus 'world' is there from the earliest beginning, the basic setting for experience – a horizon of co-reality thrown open by the mere transcendence of want which widens the seclusion of internal identity into a correlative circumference of vital relationship. (Jonas, 1966, pg. 84)

Thus, from the quote above, we see how the basic drive of metabolism may perhaps be responsible for the organism's first instance of sense-making. In support of this idea, it is often

pointed out by enactive theorists that even a single celled bacterium must metabolize sucrose in order to survive, and in order to do this successfully a bacterium must have some positive valence towards sugar. In other words, a bacterium must be able to transcend its current state in order to maintain its viability, and so even a bacterium must be sense-making. The question now is whether this notion of sense-making can also be applied to groups of multicellular organisms.

Higher-Level Autopoiesis

As explained above, the enactive paradigm is centered on the concept of autopoiesis. Thus, before considering whether or not the enactive approach can be applied to groups of multicellular organisms, such as super-organisms, we must first consider whether or not these types of higher-level systems can be understood as autopoietic. However, in order to properly address this question, we must first consider the fact that the concept of autopoiesis was originally designed to describe a pattern of self-production *in the molecular domain* (Thompson, 2007, pg. 106). In other words, the concept of autopoiesis was originally meant to describe the scale of organization at which molecules interact, and not the scale at which cells and multicellular organisms interact. Of course, multicellular organisms and groups of animals are *also* composed of interacting molecules; however, when we speak of such systems, we are ordinarily referring to systems whose components are properly understood to be cells and multicellular organisms, respectively, and not protein molecules, for example. It is for this reason that the single celled organism – like our bacterium mentioned above – is considered to be the paradigm case of an autopoietic system, as a single cell is the most obvious example of a self-producing system whose basic components are properly understood to be molecules (ex. proteins, lipids, amino acids, etc.). It might also be noted that prokaryotic cells are generally considered to be the *minimal* case of an autopoietic

system, because, unlike eukaryotic cells, the components of prokaryotic cells are not isolated into compartments, such as nuclei, for example (Thompson, 2007, pg. 107).

However, despite its genesis as a theory of molecular systems, the concept of autopoiesis also appears to characterize the organization of many living systems at higher levels of biological organization as well. For example, a multicellular organism also appears to be self-producing, in the sense that its pattern of organization creates a network of cells, which form a boundary that is essential to the maintenance of its organization. In this way, multicellular organisms appear to be autopoietic at the level of multicellular organization, although this phenomenon does not necessarily guarantee that they are also autopoietic in the molecular domain. It is for this reason that the distinction between first order and second order autopoiesis was introduced (Thompson, 2007, pg. 106).

Crucially, second order autopoietic systems, such as animals and insect colonies, have been conceived of as being built of first order autopoietic components, such as cells. This distinction being made, it is still possible that second order autopoietic systems might *also* be first order autopoietic systems, and there is now evidence that metazoans, for example, may indeed be autopoietic in the molecular domain (Thompson, 2007, pg. 106). However, as Evan Thompson points out, "in determining whether a given system qualifies as autopoietic, much depends on how we interpret "boundary" and "internal reaction network" in the criteria for autopoiesis" (Thompson, 2007, pg. 106). It is questions such as these that have prompted me to incorporate the notion of *sympoiesis* into my analysis; however, before discussing the notion of sympoiesis, it will be helpful to consider some early comments made by Humberto Maturana on the organization of higher-level systems.

In his 1970 paper entitled *The Biology of Cognition*, Maturana explains the idea of third

order self-referring systems, saying:

> The society of bees (the honey producing bees) is an example of a third order self-referring system...it has a circular organization superimposed on the second order self-referring systems that are the bees, which in turn have circular organization superimposed on the first order living systems that are the cells; all three systems with their domains of interactions are subordinated both to the maintenance of themselves and to the maintenance of the others. (Maturana, 1970, pg. 11)

Through this concept of third order self-referring systems we may begin to gain a better sense of how the autopoietic pattern of organization might be understood to operate across numerous levels of biological organization, eventually reaching the level of a super-organism. In this regard, it may also be worth noting that Varela and Maturana have also suggested that there is "an ever present selective pressure for the constitution of higher order autopoietic systems from the coupling of lower order autopoietic unities" (Varela, Maturana, 1973, pg. 111). For this reason, there may be good theoretical ground for investigating the possibility that certain tightly coupled groups of multicellular organisms, such as super-organisms, might also be understood as first order autopoietic systems. However, by incorporating the notion of sympoiesis into our analysis, we may begin to apply the enactive approach to these kinds of higher-level systems prior to answering the question of first order autopoiesis conclusively, as I will argue shortly.

Social Autopoiesis

Despite the notion of third order self-referring systems, there is still much uncertainty surrounding the idea that groups of multicellular organisms might be governed by higher-level patterns of autopoiesis (even if these groups are considered to be second order autopoietic

systems, and not first order autopoietic systems). Perhaps this uncertainty has arisen because the notion of second order autopoiesis has most often been applied to groups of humans, rather than colonies of insects, and this focus on human *social* organization can be problematic for several reasons. However, before addressing some of these difficulties, let us first consider some of the reasons why social theorists might apply the concept of autopoiesis to human social groups in the first place.

For starters, the concept of autopoiesis seems to capture the sort of higher-level autonomy characteristic of many forms of human social organization. It also captures the phenomenon of emergence that seems to characterize many social groups, as well as the way in which the identities of social systems can appear to persist despite a constant change in membership (Mingers, 1995, pg. 119). For example, many types of social organizations, such as schools, religious groups, and businesses, emerge out of a network of interacting individuals, and the structures of such systems often appear to be maintained despite changes in membership. To take a specific example, the notion of autopoiesis may be of use in explaining the way in which a corporation can change its board of directors, and yet maintain a fixed identity in the eye of the public. Despite this apparent consistency, however, it is still unclear whether a social group, such as a corporation, can be understood to be self-producing in the same way that a single celled bacterium might. As Mingers points out, "the central problem is that the autopoietic definition specifies the production of the components constituting the entity and the production of a boundary separating the entity from its environment. The definition does not specify that these must be physical components, but if they are not, then what precisely is their domain of existence?" (Mingers, 1995, pg. 120). In other words, it is unclear whether a "board of directors" can be considered a component of an autopoietic system in the same way that a protein might,

for example. Additionally, even if one were to consider the individual members on a board of directors to be the components of the system, these individuals were presumably produced through biological processes that lie outside of the system itself, and they were most certainly not produced through any processes that were *essentially* related to the organization of the corporation. However, even though the above example fails, there may still be certain instances in which the individuals who participate in a social system could be understood to count as the system's self-produced components. After all, while this may not be true for a large corporation, the individuals that participate in a human family, for example, do appear to be produced by earlier generations of organisms within the same system (i.e. their parents), and these organisms may then produce future generations of organisms themselves (i.e. their children). In this way, the structure of a human family may perhaps be understood to operate through a higher-level pattern of autopoietic organization. There are, however, certain problems with this example as well.

For starters, familial relations such as 'mother', 'father', and 'child' are social identities and not biological structures in themselves. As Mingers points out, "the actual production of biological organisms is a biological process quite independent of whether such organisms then participate in a social family" (Mingers, 1995, pg. 128). Moreover, even if we do consider parents to be the biological producers of their children, it is clear that children do not have the same reciprocal influence on the biological structures of their parents (except perhaps during the 9 months of pregnancy, at which time the structure of the mother and the structure of the foetus may perhaps be considered co-constitutive). It is for reasons like these that it is hard to imagine how one might understand the members of a human family to be the biological components of a second order autopoietic system.

Another difficulty in applying the notion of autopoiesis to social groups is to identify the boundaries of such systems. In the case of a human family, for example, the members of the family may have various degrees of biological relation and their social inclusion in the family structure may change over time (Mingers, 1995, pg. 126). Additionally, in order to identify the topography or contour of a social group, such as a family, an observer must have some way of coupling to the *entire* system, and not just to those particular individuals that compose the system. In other words, in order to determine the boundaries of a social group, an observer must be able to couple with the entire system from a sufficient spatial and temporal distance, and the bigger and more complex the components of such a system are, the more difficult this coupling may be.

This is yet another reason why the study of the social insects may prove to be particularly advantageous when considering the idea of group-level autopoiesis, as the individual organisms that compose an insect colony are relatively small from the perspective of human beings, and so their global organization may be more easily mapped. In fact, there has already been a great deal of research into the structures of insect colonies, and our understanding of their social organization is in many cases fairly well established (Hölldobler and Wilson, 2009; Seeley, 2005). However, before considering the idea that certain colonies of insects may be organized through higher-level autopoiesis, I will first discuss the role that the observer plays in the identification of autopoietic systems. This discussion may help to clarify how it is that a higher-level system, like a super-organism, could be understood to operate as a structurally distinct entity at a higher-level of biological organization, and yet still appear like a distributed group of organisms from the perspective of a human observer. By addressing this type of observational (and conceptual) bias, I hope also to clarify why it is that the idea of collective cognition may

perhaps seem so counter intuitive, despite also being so familiar.

Observer-Dependency

The concept of autopoiesis is heuristic device, or a conceptual aid, that can help us to better understand living systems and processes of cognition (Thompson, 2010, pg. 50). This implies that an observer must take a stance on what constitutes a system when determining whether or not that system can be understood as autopoietic. In other words, the identification of an autopoietic system is both interest-relative and observer-dependent. A given network of processes may appear autopoietic when observed at the level of the cell, for example, but may no longer appear autopoietic when observed through an electron microscope. Similarly, the same network of processes may no longer be understood to be autopoietic when considered in relation to the broader ecosystem in which it participates. For this reason, even if we follow the enactive approach, and take autopoiesis to be the defining characteristic of all living systems, we still cannot escape the role that the observer plays in the identification of such systems. This kind of observer-dependency may partly explain our reluctance to identify higher-level systems, such as super-organisms, as autonomous living entities, capable of cognition.

This idea of observer-dependency may perhaps be most easily addressed by considering the relationship between an observer and a multi-cellular organism. For example, it is certainly true that a multicellular organism may appear like a bounded and self-produced system when observed at the macroscopic level of the animal. In fact, this is precisely the type of system that Varela and Maturana had in mind when they proposed the idea of second order autopoietic systems, as already discussed (Varela, Maturana, 1973, pg. 110). However, it is only when we observe a multicellular organism in its entirety that its components appear to be organized

through second order autopoiesis. If, for example, we were able to observe its components from the lower-level perspective of its cells, its structure might begin to appear more like an open environment in which every individual cell competes for survival. In other words, if we were to shift our perspective to a lower level of observation by using a microscope, for example, the multicellular organism might begin to appear more and more like the niche of its cells, and its second order autopoietic organization may be increasingly difficult to identify. This is not to say that the organization of the multicellular organism actually changes as we shift our perspective, but its organization *appears* to change as we shift our perspective. What this sort of perspectival variability indicates, therefore, is not a changing pattern of organization, but rather a difference in the way that we perceive and understand the organization of living systems, depending on our perspective, and our interests at the time of observation.

Given this kind of observational bias in the identification of living systems, it is therefore conceivable that certain networks of biological processes may be best understood as autopoietic, but that these patterns may be as yet unrecognizable given our current perceptual and technological capabilities, or our present criteria of observation. It is possible, for example, that certain higher-level systems, which are not currently recognized as autopoietic, may eventually be considered to be autopoietic once new technologies are developed that expand our observational scope, or once the appropriate processes are included in our understandings of these systems. As I will argue, this may be happening in the field of sociobiology, as there is increasing indication that certain colonies of eusocial insects are so well organized at the level of the group that whole colonies might be regarded as distinct biological structures – "super-organisms" in their own right.

Given the above considerations, it is certainly possible that different heuristic devices

may be needed in order to fully understand the various levels of biological organization at which we observe living systems. However, rather than introducing a radically different heuristic device for every level of biological organization that we observe, it may be possible to expand our existing notion of self-production in order to account for these other levels. In fact, as mentioned above, the notion of second order autopoiesis has already been introduced in order to better explain the biological organization of certain higher-level systems, such as multicellular organisms. However, although the notion of second order autopoiesis may be very helpful when considering the organization of multicellular organisms, we have already noted some of the ways in which the concept may fail to capture the kinds of organization that are exhibited by even higher-level biological systems, such as super-organisms. There is, however, another heuristic device that may be better suited to these kinds of higher-level systems, while at the same time remaining highly integrated with the autopoietic account of living systems, as well as the enactive theory of mind: the concept of *sympoiesis* (Dempster, 2000).

Sympoiesis

The term *sympoiesis* means "collective-production." Beth Dempster introduced the concept primarily in order to describe a pattern of organization that characterizes higher-level biological systems, such as ecosystems – systems that appear to be living but that do not meet the traditional criteria of autopoiesis (Dempster, 2000). Such systems might typically include animal groups and ecosystems, for example, although the concept may perhaps also be used to describe even higher-level biological systems as well, such as the earth's biosphere. As Dempster explains:

> Sympoietic systems are characterized by complex interactions among

> components and relations that recursively produce and maintain a self-similar, dynamic organization of evolving, interdependent complexity that is distinguishable as some sort of 'whole' or entity, yet has neither temporal nor spatial boundaries. Rather than maintaining their 'wholeness' through the delineation of boundaries, it is maintained by dynamic interdependencies and an interactive, balancing tension among components, processes and influences. (Dempster, 2007, pg. 94)

From this definition we can see that sympoietic systems have much in common with their autopoietic counterparts, except that they lack self-defined boundaries and are collectively produced. Importantly, Dempster also conceives of sympoietic systems as being *organizationally ajar*, as opposed to organizationally open or organizationally closed (Dempster, 2000, pg. 5).

To better understand this notion, let us consider the classic example of an ecosystem (Dempster, 2000). At firsts glance, an ecosystem may appear to be characterized by an autopoietic pattern of organization. For example, ecosystems appear to maintain a certain equilibrium, which sets a limit on the types of organisms that can survive within them. An organism that has evolved in a dry environment, for example, will generally not survive within a wet environment, and those organisms that do survive will generally have been produced from within the wet environment itself, or at least from within a similar environment (Dempster, 2000, pg. 9). Thus, there is a sense in which ecosystems mostly seem to produce their own components (i.e. the organisms that inhabit them). However, in this example, a distinction between autopoiesis and sympoiesis can be recognized when one considers that, unlike an autopoietic system, an ecosystem *may* incorporate external elements into its structure, which may then begin to shape its broader pattern of organization. For example, if the seeds from a dry environment

manage to survive in a wet environment, they may then begin to shape the overall organization of that wet environment, provided that the other biological systems within the environment also begin to adapt in relation to them. This suggests that sympoietic systems, such as ecosystems, are *organizationally ajar*, unlike autopoietic systems, which are organizationally closed, because ecosystems are partially open to external information that can change their overall patterns of organization. However, at the same time, even though sympoietic systems may be characterized by a certain degree of organizational openness, these systems are still understood to exhibit certain degrees of organizational closure as well, resulting from the dense structural couplings of their component organisms (Dempster, 2000).

One might still be tempted, however, to describe ecosystems as autopoietic because they often appear to have self-defined boundaries. For example, forests are often described has having tree lines. However, as Dempster points out, there are often islands of trees beyond the tree line and "...even if considered as boundaries, these lines are either determined by the environment (hence are not self-defined) or, the environmental factors determining the edge must be considered part of the system, in which case the boundary would not be at the tree line" (Dempster, 2000 pg. 8). Thus, the problem of boundaries provides yet another reason for conceptualizing ecosystems as sympoietic. However, one might still object that while the boundary of an ecosystem may be difficult to discern at the level of human observation, it might appear much more impermeable if one were able to 'zoom out' and observe it from a broader spatial and temporal perspective. In other words, one might argue that because human beings are embedded within ecosystems, it may be especially difficult for us to couple with these systems from a sufficient spatial and temporal distance to properly identify their boundaries. It is for reasons like these that one should always bear in mind that although certain higher-level

structures, like ecosystems, may appear without boundaries from the perspective of human observation, this does not necessarily mean that they lack boundaries in any absolute sense – it is possible that their boundaries may be simply difficult to discern given our own level of biological organization.

Before moving on to a discussion of super-organisms, it is important to note that the concept of sympoiesis, as conceived by Dempster, is a heuristic device that allows us to conceptualize the patterns of living systems in relation to a *continuum*. In other words, sympoiesis is not considered to be a pattern of organization that actually exists in nature, but is rather considered to be an *ideal* pattern of organization, at one end of a conceptual continuum, with ideal autopoiesis at the other (Dempster, 2000, pg. 6). For instance, even a prokaryotic cell cannot be considered to be autopoietic in the ideal sense, even though it is considered to be the minimal and best understood case of an autopoietic system, because there still exists a certain ambiguity as to what constitutes its internal reaction network when one considers the problem of determining the *exact* point at which its food has been metabolized, for example. It is for reasons like these that, according to Dempster, the patterns of organization that characterize living systems should be conceptualized as emerging somewhere along a continuum. In this way, the notion of sympoiesis (and the corresponding concept of "organizationally ajar") may allow us to conceptualize living systems in terms of their *degrees* of boundedness and organizational closure, for example. By incorporating the notion of sympoiesis into my analysis, therefore, I am not suggesting that certain groups of multicellular organisms, such as super-organisms, are actually governed by a sympoietic pattern of organization; rather, what I am suggesting is that such systems may be better understood by considering their approximate (and relative) locations along a continuum of organizational closure. By conceiving of all living systems as emerging

along a continuum, I believe it may be possible to conceive of super-organisms as operating more towards the sympoietic end of the spectrum, and yet still establishing sufficient degrees of organizational closure to allow for enaction. In other words, even though the enactive approach is centered on the idea that cognition is grounded in autopoiesis, when autopoiesis is understood to be an *ideal* pattern of organization, it may then be possible to conceive of cognition as emerging in sympoietic systems as well – systems such as super-organisms.

Part 2: Super-organisms

The term *super-organism* was invented to describe those groups of organisms that appear to have formed higher-level biological units as a result of their collective patterns of organization. This term can be applied quite generally to many different types of animal groups, however I will mostly be using it to refer to certain networks of highly organized social insects such as ants, bees, wasps, and termites. For our purposes, therefore, let us take a definition of a super-organism that was proposed by the insect sociobiologists Hölldobler and Wilson:

> The term *superorganism* may be applied only to colonies of an advanced state of eusociality, in which interindividual conflict for reproductive privilege is diminished and the worker caste is selected to maximize colony efficiency in intercolony competition. (Hölldobler and Wilson, 2009, pg. 9)

As mentioned above, I will attempt to apply the enactive approach to super-organisms, via the concept of sympoiesis, in order to show that these systems can be understood as collectively cognitive. In order to do this, we must therefore first establish to what degree these groups of organisms can be understood as sympoietic and to what degree they can be understood as autopoietic. Fortunately, the groups of insects that meet the above definition of a super-organism

tend to be relatively simple in terms of their higher-level patterns of organization, and so it may be relatively simple to determine at what point they fall along the autopoietic-sympoietic continuum. As Hölldobler and Wilson explain:

> The super-organism exists at a level of biological organization between the organisms that form its units and the ecosystems, such as a forest patch, of which it is a unit… [In such systems,] the lower-level units in this case, the organisms, are relatively simple in the way they interact to create colonies, and thus, the colonies themselves are not nearly so complex in structure and operation as cells and ecosystems. Both of these levels, organism and colony, can be easily viewed and experimentally manipulated. (Hölldobler & Wilson, 2009, pg. xviii)

For this reason, an investigation of the insect super-organisms may also be the ideal method for uncovering some of the possible mechanisms or "technologies" behind sympoietic organization, as will be shown below.

Let us begin by considering one of the most well known and best understood examples of a super-organism – a colony of honeybees. A typical colony of honeybees is composed of many thousands of bees, all of which possess substantially different genotypes despite being produced by a single reproducing queen (Seeley, 1995, pg. 7). This great variety of genotypes is due to the "...segregation and recombination of a queen's genes during meiosis, and because a queen typically mates with 10 or more males" (Seeley, 1995, pg. 7). Ordinarily, one would expect such a vast pool of genotypes to lead to conflict within the colony as a result of individual competition, however very little conflict occurs within the hive, and the colony, as a whole, is able to function as a single cooperative unit (Seeley, 1995, pg. 7). This high level of cooperation is thought to occur because worker bees are best able to serve their genetic interests by serving

the collective interests of the colony. For instance, by working together, a colony of honeybees has a better chance of out-competing neighbouring colonies for resources. Over the course of evolution, this kind of between-colony competition may lead to an increase in the genetic material of those individuals belonging to the more successful colony, relative to the genetic material of those individuals belonging to the less successful neighbouring colonies (Seeley, 1995, pg. 9). In other words, as a result of between-colony competition, colonies of honeybees may begin to develop distinct *aggregates* of genotypes. Moreover, it appears that as these different colonies continue to compete over the course of evolution, their distinct aggregates of genotypes may then become the target of natural selection (by way of the aggregates of phenotypes through which they are expressed). And, by acting on a colony's aggregate of genotypes, natural selection may therefore be able to shape the emergent properties of a colony as a whole. For example, there is increasing indication that colony-level natural selection is operating on the development of caste systems in certain types of eusocial insects. As Hölldobler and Wilson explain, "the demographies and sociobiological traits of the colony members are shaped not by each individual's direct genetic fitness but by the summed effects of all their performances on the fitness of their colony...there can be little doubt that the target of selection moulding caste systems is the emergent properties of the colony" (Hölldobler and Wilson, 2009, pg. 155).

Emergent Behaviour

The emergent behaviours of super-organisms are generally understood to occur as a result of the summed effects of the behaviours of those individual organisms that compose them.

Interestingly, the emergent behaviours of super-organisms can often appear to be highly coordinated, despite the fact that these higher-level systems also appear to lack any central control. For this reason, the coordinated behaviours of super-organisms are thought to be *emergent* properties of the group, resulting from a distributed control system that spreads across its entire structure (Hölldobler and Wilson, 2009, pg. 58; Seeley, 1995, pg. 259). In a colony of honeybees, the emergent behaviour of pollen foragers ensures that the hive's total supply of pollen is maintained at an optimum level. The colony is able to do this, not through hierarchical chains of command, but through distributed and indirect cues sensed by the individual pollen foragers. As Thomas Seeley explains, "even though the control of a colony's pollen intake is broadly distributed among its members, coherent regulation nevertheless occurs because the behaviour of each pollen forager is ultimately linked to a single shared variable, the size of the colony's pollen reserve" (Seeley, 1995, pg. 256). He goes on to say that these same pollen foragers "which apparently know nothing about their colony's internal supply of pollen or its demand for pollen, are able to modulate their behaviour properly by detecting changes in their protein levels" (Seeley, 1995, pg. 257). This kind of distributed control is considered to be a characteristic of a sympoietic system (Dempster, 2000, pg. 7).

Aside from environmental factors, such as the example of pollen supply mentioned above, the emergent behaviours of super-organisms are also partly determined by the phenotypes of the individual organisms that compose them. This is to say, the emergent behaviours of super-organisms are also partly determined by the bodily affordances of those organisms that compose them, and these bodily affordances are contingent upon phenotypes – phenotypes that may have evolved as aggregates in processes of group-level natural selection. This suggests that even the individual behaviours of a super-organism's component-organisms may have been shaped by the

evolutionary dynamics of the group. In other words, there is a sense in which the dynamic, emergent behaviours of a super-organism may be able to feed forward to influence the behaviours of those organisms that compose it, by altering their phenotypes over an evolutionary time-scale. For this reason, super-organisms may be subject to evolutionary feedback.

Evolutionary Feedback

Generally speaking, there are two types of evolutionary feedback that may affect the emergent behaviours and properties of super-organisms – positive and negative. On the one hand, positive evolutionary feedback is said to occur when the eusocial behaviour of a group of organisms leads to higher-level adaptations that increase the reproductive-rates of those individual members who possess the eusocial traits. This means that any cooperative behaviour that is evolutionarily advantageous – such as the pollen foraging behaviours of honeybees – may lead towards increased cooperative behaviour in future generations as a result of the increased frequency of 'cooperative phenotypes'. In this way, successful higher-level adaptations may lead to an increase in the frequency of the eusocial traits that gave rise to them, which may further strengthen the system's higher-level adaptions, thus leading to a further increase in eusocial traits, and so on, in an ongoing cycle of positive evolutionary feedback. Given enough of this positive evolutionary feedback, a super-organism may emerge.

On the other hand, negative evolutionary feedback is said to occur when higher-level adaptations no longer prove advantageous for those individuals in the group who possess the eusocial traits that gave rise to the higher-level adaptations. In this case, negative evolutionary feedback may decrease the frequency of the group's aggregate of eusocial traits in future generations, along with the group's higher-level adaptations themselves (Hölldobler & Wilson,

2009). This suggests that higher-level systems, such as super-organisms, need not necessarily become increasingly integrated over the course of evolution, but that they may also begin to disassemble if negative evolutionary feedback persists. In other words, the component-organisms of higher-level systems, such as super-organisms, may also begin to de-couple, which would make their higher-level patterns of organization become disorganized or non-existent. Therefore, given enough negative evolutionary feedback, a super-organism may also begin to disappear.

Given the notions of positive and negative evolutionary feedback discussed above, we may begin to get a sense of how it is that living systems might be understood to operate with different degrees of organizational closure, depending on the degrees of positive and negative evolutionary feedback to which they have been exposed. This is of course further ground for incorporating Beth Dempster's notion of sympoiesis into our analysis, as their model places living systems on a continuum, thus allowing for various degrees of organizational closure in these systems. In this regard, it may also be helpful to make an even further distinction, in order to capture the degrees of organizational closure that are possible in organizationally ajar, sympoietic systems, like super-organisms.

Strong Organizational Closure/Weak Organizational Closure

I propose the concepts of *strong organizational closure* and *weak organizational closure* in order to help us further conceptualize the spectrum of organizational closure that is theoretically possible within sympoietic systems. For instance, in a colony of ants, strong organizational closure may perhaps be understood to have occurred when the colony has evolved various castes whose distinct phenotypes have become *essential* to the colony's overall survival, and thus also essential to the survival of the genetic material of those individuals that compose the colony. In

this example, the information contained within the system (i.e. the genetic material of the individual ants) has become so entangled with the overall structure of the colony that it has become virtually impossible for this information to escape the 'boundaries' of the system (in this case, the territorial boundaries of the colony). For a colony of ants with such a high degree of intra-colony interdependence, the components of the system (i.e. the individual ants) are practically unable to survive, on the long term, without the intra-colony relations that the system (i.e. the colony) provides. This is to say: the system would have a strong tendency to breakdown if not for the relations between its components, unlike a system with weak organizational closure, whose structure might be more resilient to the loss of individuals.

Given this idea that living systems emerge along a continuum, with various degrees of organizational closure, if strong organizational closure were to increase in certain sympoietic systems as a result of positive evolutionary feedback, these systems might then begin to exhibit characteristics that would normally be attributed to autopoietic systems. For example, if a colony of ants were to develop strong organizational closure, and the survival of the colony's genetic material became increasingly dependent on higher-level adaptations, the super-organism might appear to establish a more finite temporal trajectory, much like an autopoietic system. As Dempster explains, "[autopoietic] systems have clearly defined temporal, as well as spatial, boundaries…the significantly different characteristics of sympoietic systems give them potentially infinite trajectories. This makes definition of developmental stages, 'beginnings,' and 'ends' – their temporal boundaries – also difficult to delineate in a non-arbitrary manner" (Dempster, 2000, 11). This suggests that if sympoietic systems, like super-organisms, were to develop strong organizational closure (and thus become increasingly autopoietic), they might begin to develop the appearance of a life span, or a temporal contour. In other words, given the

notion of strong organizational closure, there is a sense in which a super-organism might be able to die, for example, in a way that a more amorphous evolutionary system may not.

Higher-Level Adaptivity

As discussed above, it is the aim of this paper to show that the enactive approach allows us to understand super-organisms through the idea of collective cognition, provided that we incorporate the notions of sympoiesis and strong organizational closure into our account. In order to show how this is possible, I will argue that certain super-organisms may be sufficiently organizationally closed that they are able to co-constitute higher-level niches, within which their component-organisms may collectively enact meaningful, higher-level behaviours. In this way, I aim to show that it is conceivable certain super-organisms might be capable of both specifying their own domains of operation and then enacting meaningful behaviours within them, thus making them collectively cognitive (i.e. higher-level systems that are capable of sense-making at the group-level). However, in order to show that super-organisms can be considered sense-making at the group-level, and thus collectively cognitive, these systems must be capable of higher-level adaptivity. This is because, as Evan Thompson explains, "a distinct capacity for 'adaptivity' needs to be added to the minimal autopoietic organization so that the system can actively regulate itself with respect to its conditions of viability and thereby modify its milieu according to the internal norms of its activity...although autopoiesis is necessary for sense-making, it is not sufficient, but autopoiesis and adaptivity are jointly necessary and sufficient" (Thompson, 2010, pg. 148).

According to Ezequiel Di Paolo, the philosopher who first highlighted the importance of the concept of adaptivity for sense-making within the enactive paradigm, adaptivity can be

defined as:

> A system's capacity, in some circumstances, to regulate its states and its relation to the environment with the result that, if the states are sufficiently close to the boundary of viability,
>
> 1. Tendencies are distinguished and acted upon depending on whether the states will approach or recede from the boundary and, as a consequence,
>
> 2. Tendencies of the first kind are moved closer to or transformed into tendencies of the second and so future states are prevented from reaching the boundary with an outward velocity. (Di Paolo, 2005, pg. 438)

From this definition we get a sense of how environmental perturbations may become meaningful by virtue of their relationship to the organism's boundary of viability. Thus, we get a sense of how an organism's adaptivity may be the necessary precursor to its meaningful behaviour. For this reason, as suggested by the earlier quote from Thompson, enactive theorists consider adaptivity to be an important criterion for establishing whether or not a system is sense-making.

One indication that super-organisms may be capable of higher-level adaptivity is the way in which their aggregates of component-organisms appear to alter in response to environmental perturbations. For example, it appears that certain colonies of insects may be capable of adapting to their environments by varying the size-frequency distributions of their various castes. In many species of ants, for example, the size-frequency distributions of different castes can change with the production of every new brood, and these distributions may be partly determined by environmental factors (Hölldobler and Wilson, 2009, pg. 154). For example, in the early stages of many ant colonies, the queen will first give birth to many tiny worker ants, but then, after the colony has reached a certain population, the queen will begin to produce larger ants that are

capable of defending the nest (Hölldobler and Wilson, 2009, pg. 154). As this example demonstrates, it appears as though the aggregate of the colony's phenotypes may be changing in response to the state of the colony's population, which is partly determined by environmental factors, such as the availability of food. This apparent colony-level response to higher-level environmental perturbations via the plasticity of a colony's size-frequency distribution may therefore indicate that super-organisms are indeed capable of higher-level adaptivity. In the words of Hölldobler and Wilson, "the evidence is conclusive that the developmental programs leading to the physical caste systems of ants are genetically determined...indications are also very strong that the size-frequency distributions undergirding the more complex caste systems are adaptive for the colony as a whole" (Hölldobler and Wilson, 2009, pg. 152).

Higher-Level "Technologies"

In order for a living system to be adaptive it must have some way of actively monitoring its internal state in relation to the changing conditions of its environment and then be able to respond appropriately; however, in order to do this, the system must have some mechanism by which to transfer this information among its components. As Thomas Seeley explains, "the formation of a higher-level unit by integrating lower-level units will succeed only if the emerging organization acquires the appropriate 'technologies' for passing information among its members" (Seeley, 1995). For this reason, in order to be adaptive at the group-level, super-organisms must have some mechanisms by which they transfer information about their collective-states to their component organisms, and vice versa. In other words, they must have developed certain 'technologies' of global-local information transfer.

Indeed, there is increasing indication that certain super-organisms have developed such

'technologies', as is evident in Thomas Seeley's book *The Wisdom of the Hive* (Seeley, 1995). For example, in colonies of honeybees, the emergent behaviour of pollen foragers occurs as a result of the ways in which individual pollen foragers respond to protein levels, as was already mentioned above. Thus, to adopt Seeley's terminology, one such 'technology' of global-local information transfer in honeybees may be understood to function through the foragers' ability to detect protein levels. In other words, for honeybee colonies, it seems as though protein levels have become a variable that convey information about their collective-state, thereby modulating certain group-level behaviours. The foragers' ability to detect and respond to protein levels might therefore be acting as a 'technology' that facilitates both the maintenance and the distributed control of the super-organism. Through protein levels, information is passed between members of the colony *indirectly*, so protein levels may be understood to serve as a form of global-local feedback between the higher-level structure of the colony and the lower-level structures of its component organisms. In this way, a colony of honeybees may be understood to monitor its internal state via the protein-level detections of individual pollen foragers, and then respond to that state via the emergent higher-level behaviours of those same foragers. For this reason, a colony of honeybees may perhaps be regarded as self-monitoring system, or, more accurately, a collectively-monitoring system.

Another possible example of such higher-level 'technologies' in honeybees might be found in the fact that foraging bees have evolved the ability to perform meaningful behaviours called 'waggle dances', which communicate information about the direction and quantity of external resources. Honeybees have also evolved the ability to recognize various cues within the hive that indicate precisely which waggle dances should be acknowledged given the total material and energy requirements of the hive (Seeley, 1995; Hölldobler, Wilson, 2009). As a

result of these types of 'technologies', a colony of honeybees is able to function as a highly efficient unit of biological organization. As Hölldobler and Wilson explain, "the bees detect shortages of foragers and food storers by the increase or decrease of waggle and tremble dancers. Through the constant flow of such cues and signals, the colony – the super-organism – works remarkably well as a unified whole in securing its food supply" (Hölldobler, Wilson, 2009). Thus, as a result of this type of top-down feedback, it may not only be the summed effect of the behaviours of individual bees that determines the emergent behaviour of the colony, but also the dynamic nutritional requirements of the colony *as a whole*. In other words, it is conceivable that the state of the colony – and in particular its viability conditions – may help to determine the emergent behaviour of the super-organism. For this reason, the entire colony of honeybees may perhaps be regarded as a kind of higher-level metabolic structure – a living system that collectively-manages its own flow of matter and energy in order to collectively-discover and collectively-process the new, external material that is necessary to maintain its higher-level of organization. Moreover, if a colony of honeybees can be understood as a kind of higher-level metabolic structure, then, according to the enactive approach (and the philosophy of Hans Jonas mentioned earlier), it might also be understood to be collectively sense-making. In other words, the higher-level 'technologies' of honeybees may allow us to conceive of these systems as collectively cognitive.

Part 3: Collective Cognition

Now that we have established a framework for understanding the concept of collective cognition, we may be in a position to discuss some of the possible mechanisms of its emergence. However, before exploring these ideas in more detail, I must first discuss *sensorimotor contingency theory*

(Noë, 2006), as this enactive theory of perception will form the basis of my hypothesis.

Sensorimotor Contingency Theory

To begin, sensorimotor contingency theory is an enactive theory of perception, as mentioned earlier. Thus, the theory takes the total organization of the organism as its basis. In brief, sensorimotor contingency theory proposes that as an organism learns to move its body, its movements begin to shape its perception, and vice versa, such that the organism develops a pre-reflective bodily understanding of the contingencies that exist between its movements and its sensory experience. This type of pre-reflective bodily understanding of sensorimotor contingencies is called *sensorimotor know-how* (Noë, 2006).

Let us consider this idea by looking at an example, such as the perception of an object in the distance. Under normal circumstances, as one approaches an object in the distance, one has an implicit, pre-reflective bodily understanding that the object will begin to appear larger in the visual field as one continues to move closer. One does not perceive a 'tiny' apple on the top branch of an apple tree, for example, and expect that the apple will remain tiny as one climbs to the top of the tree. Rather, one has an implicit understanding that the apple on the tree will be of normal apple-size when one reaches the top. Such implicit, pre-reflective bodily understanding, or sensorimotor know-how, is based upon one's previous experience with objects in the distance, as well as the ways in which one's perceptions of those objects have previously altered in response to one's movements. This is to say: there is a way in which our perception of the world has grown intimately interconnected with both the histories and the structures of our living bodies, such that our perceptions and our movements have become inextricably intertwined. This intertwining of sensorimotor contingencies runs so deep that if an object in the visual field did

not begin to appear larger as one moved towards it, the object might begin to appear like an illusion, or the entire world might even begin to distort (as will become evident from an example that we will consider shortly). This type of sensorimotor contingency, between bodily movement and the perceived size of an object, is just one example of the many ways in which bodily affordances and perceptual experience have become entangled over the course of development and evolution, resulting in the phenomenon of sensorimotor know-how. Again, this idea of sensorimotor know-how has much in common with Merleau-Ponty's concept of the body schema (Merleau-Ponty, 1962), and is also a phenomenon that has been explored by Heidegger through his notion of the *ready-to-hand* (Heidegger, 1962).

As already alluded to, in order to better illustrate this idea of sensorimotor know-how, we will now consider one particularly striking example of the phenomenon – the experiment of the inverting glasses. In this experiment (which is a favourite of Alva Noë), a subject is asked to put on special 'inverting glasses' that are designed to invert the direction of incoming light. When the subject puts on the inverting glasses, light entering through the right lens is directed to the left eye, and light entering through the left lens is directed to the right eye. Now, under these circumstances, one would normally expect the visual scene to be completely reversed, such that objects on the subject's right appear to be on the left, and objects on the subject's left appear to be on the right. However this is not the case – when the subject puts on the inverting glasses, objects become distorted, not inverted.

According to sensorimotor contingency theory, the perceptual distortion caused by the inverting glasses occurs because the subject no longer understands how their bodily movement is related to their vision, and so they are no longer able to make sense of the visual data that they receive. In other words, when wearing the inverting glasses, the subject loses their sensorimotor

know-how. Alva Noë explains the phenomena as follows:

> [The subject] receives exactly the stimulation he would receive were he looking at an object in a different spatial location without inverting lenses. The inability to see normally stems not from the character of the stimulation, but rather from the perceiver's understanding (or rather failure of understanding) of the stimulation...The basis of perception, on [the] enactive, sensorimotor approach, is implicit practical knowledge of the ways movement gives rise to changes in stimulation. When you put on the distorting lenses, the patterns of dependence between movement and stimulation are altered. This alteration has the effect of abrogating sensorimotor knowledge or skill, even though there is no change in the intrinsic character of stimulation. As a consequence, movements of the eye and head give rise to surprising and unanticipated changes in sensory stimulation (Noë, 2006).

Interestingly, when the subject is allowed to explore the world for a period of time while wearing the inverting glasses their perception gradually begins to become clear again, only their visual experience is *not* inverted. Instead, the subject's perception begins to appear as it did before they put on the inverting glasses, with objects on the right appearing on the right, and objects on the left appearing on the left. According to sensorimotor contingency theory, this lack of inversion suggests that the subject is able to establish a new pre-reflective bodily understanding of the contingencies that exist between their living body and the inverted visual data that they receive, such that they begin to compensate for the inversion, and are once again able to perceive the world as it relates to their living bodies. In other words, by uncovering new sensorimotor contingencies that exist while wearing the inverting glasses, the subject is able to re-establish

sensorimotor know-how, and their perceptual experience is no longer distorted by the inversion of visual information.

Higher-level Sensorimotor Know-how

As we have seen, a change in sensorimotor contingencies can affect the way in which an organism perceives the sense data that it receives. For this reason, it is conceivable that as the higher-level structure of a super-organism emerges, so too may higher-level sensorimotor contingencies that may effect the perceptual experiences of the organisms that compose it. For example, the temperature of a honeybee hive must be maintained within a certain range if the colony is to survive, however the overall temperature of the hive can vary as a result of individual behaviours, such as the flapping of wings or the gathering of water (Seeley, 1995). Thus, by linking their individual behaviours with variations in hive temperature, it is conceivable that the individual honeybees may begin to gain an increasing sensorimotor know-how of their embeddedness within the higher-level structure of the colony. In other words, it is conceivable that as individual behaviours become increasingly correlated with higher-level structural changes, such as variations in hive temperature, individual honeybees may begin to develop increasing sensitivity to their own sensorimotor embeddedness within the higher-level structure of the colony, perhaps allowing them to collectively develop *higher-level sensorimotor know-how*.

In order to better understand this idea of higher-level sensorimotor know-how, it may perhaps be helpful to consider an analogy drawn from humans. Consider the phenomenon of a dance-floor, for example, which is, incidentally, also a metaphor that is often used to describe a beehive. On a dance-floor, human beings may appear to have a high degree of freedom, for

example, however, there is still a way in which the higher-level sensorimotor dynamics of a dance-floor can have a subtle (and a not-so-subtle) constraining effect on the movements of individual dancers. There is a way in which one's ability to cross a dance-floor may require 'dancing one's way through', for example, and this type of behaviour may be not only functional but also meaningful. Importantly, there is even a way in which the combined movements of interacting dancers can sometimes result in higher-level patterns of collective behaviour, such as the emergence of a mosh-pit, for example, or some other spontaneous crowd formation. It is also important to note that these sorts of spontaneous higher-level formations are often sensed by individuals *prior* to their occurrence, through subtle (and not-so-subtle) sensorimotor interactions with their neighbours. One might sense the possibility of an emerging conflict through the tension of those around, for example, and may perhaps even get the sense that the wrong movement might trigger that atmosphere of conflict. Of course one might also begin to sense this kind of tension through more direct means, such as when one overhears an argument, for instance; however, the point is that *with increasing sensorimotor couplings between agents may come an increasing sensitivity to collective dynamics, and this may begin to alter individuals' sensorimotor know-how in relation to the collective state*.

To summarize, therefore, there is a way in which even human beings may begin to develop higher-level sensorimotor know-how of the groups in which they participate. In fact, philosophers within the enactive tradition have already begun to address this type of phenomenon through concepts like *participatory sense-making* and *rhythmic capacity* (De Jaegher, Di Paolo, 2007; Fuchs, De Jaegher, 2009). Interestingly, the phenomenon of group-level synchronization has even been observed at the level of the human brain. For example, there is recent evidence that the neural oscillations of interacting individuals can synchronize during

social interaction (Dumas, et al. 2010). This type of inter-brain synchronization should most certainly resonate with the notion of collective cognition, especially when one considers that the human brain is already divided into a right and a left hemisphere. In fact, this phenomenon has already prompted the emergence of a new field of science – social neuroscience.

Given the above considerations, one need only consider the extent to which the phenomenon of inter-organism synchronization might have evolved in certain super-organisms in order to get a sense of just how deeply embedded certain social insects might be within their collectively-evolved, higher-level sympoietic structures. Thus, it should be conceivable how certain social insects might have become collectively-sensitive to the higher-level sensorimotor contingencies of those super-organisms that they compose. For this reason, it may also be conceivable that the distributed sensorimotor know-how of these tightly coupled social organisms may itself have begun to synchronize over the course of evolution, such that a form of higher-level sensorimotor know-how may have begun to resonate at the level of the super-organism itself.

Higher-level Significance/Higher-Level Niche

Given what was said about positive evolutionary feedback, it is perhaps conceivable that as the individual organisms that compose a super-organism become increasingly dependent on their higher-level structure, these individual organisms may actually begin to perceive the environment through the significance that it holds for the state of their collective-structure as a whole. To put the point another way, it is perhaps conceivable that super-organisms, as higher-level collective-structures, might begin to sense their environments through the individual organisms that compose them.

In other words, just as the discovery of new sensorimotor contingencies allowed the subject with the inverted glasses to perceive the environment as it related to the structure of their living body (rather than through a perceptual inversion), perhaps the discovery of new higher-level sensorimotor contingencies may allow the individual organisms that compose a super-organism to perceive the environment through the significance that it holds of the state of the super-organism as a whole. Perhaps, as the individual organisms that compose a super-organism become increasingly interconnected over the course of their collective-evolution, they may begin to perceive the world through an increasingly collective perspective. In sum, it is conceivable that if the individual organisms that compose a super-organism were to become highly synchronized through increasing sensorimotor couplings between members, they might begin to collectively-sense higher-level environmental perturbations, and might then begin to function increasingly like the sensorimotor surfaces of a larger biological structure, with each individual organism gradually subordinating information that is relevant to its own survival in favour of information that is relevant to the survival of the group. It is conceivable that this might allow these groups of organisms to collectively-sense certain features of their environment that they would be unable to sense individually, and these new environmental features might then become a part of a collective-niche, within which they might then begin to collectively-operate. In short, it is conceivable that by collectively-sensing higher-level environmental perturbations that are significant to the viability of the sympoietic structures to which they belong, certain tightly coupled groups of organisms, such as super-organisms, might begin to co-constitute a higher-level niche, within which they might then begin to collectively-operate. This might allow these higher-level structures to collectively-enact meaningful higher-level behaviours, which might make them collectively-cognitive under the enactive theory of mind.

Of course, even if we can conceive of a higher-level niche, and we can understand how super-organisms might, in theory, be collectively cognitive, this does not necessarily entail that these systems would also be *collectively conscious*. In other words, it is possible to understand how a super-organism could be a living system with a mind without adding the further claim that it could also be aware of that mind. The higher-level behaviour of a super-organism might easily be understood to be unconscious, for example. Moreover, even if we grant that a super-organism *might* be understood to have some kind of experience, it would be incredibly difficult (if not impossible) to confirm this idea directly, as each animal is thought to live within its own private world of meaning, or *Umwelt* (Uexküll, 1934). This problem of course becomes even more difficult when the Umwelt in question belongs to a super-organism, whose collective-structure is distributed across a network of multicellular organisms.

Putting the question of consciousness aside, therefore, let us return to the idea of the higher-level niche, and explore whether there is any way that such a phenomenon might be detected indirectly. For starters, it is conceivable that the higher-level niche of a super-organism might be inferred by studying the super-organism's ability to accomplish certain tasks that its component-organisms would be unable to accomplish when acting individually. Certain types of emergent behaviour, for example, might provide some indication of an underlying collective-world of meaning when contrasted with the behavioural possibilities of lone individuals.

Consider the new types of "sense" that can be understood to emerge through the movements of certain animal groups, for instance (Morris, 2005). David Morris has discussed this phenomenon through the example of a pack of wild dogs, whose collective ability to hunt a rabbit emerges through the higher-level affordances of the pack's collective-movement (Morris, 2005). In this example, the latent possibilities of the pack's higher-level dynamics, in relation to

the changing conditions of the environment, allow the pack to open up new possibilities of rabbit hunting that would be otherwise unavailable to the individual dogs had they been acting alone. The emerging "sense" of the pack's movement comes into particular focus when the rabbit moves from a familiar forest environment to an open parking lot, at which point the latent possibilities of pack-movement result in the rabbit being surrounded by the hungry dogs (Morris, 2005, pg. 63). In this example, the 'strategy' of the pack to circle the rabbit appears to be an emergent result of group dynamics, and does not seem to entail the existence of any underlying collective-intelligence. Still, the phenomenon indicates a strong sensorimotor coupling between the dogs, and, given some degree of organizational closure, may therefore point us towards the possibility of a subtle, collective-intelligence, guiding the pack as a whole towards the collective digestion of the rabbit – after all, even a pack of wild dogs (as a dynamic system) might one day form a super-organism if positive evolutionary feedback led it towards strong organizational closure.

Conclusion

Given the enactive approach to cognitive science and the additional concept of sympoiesis, it appears that certain tightly coupled groups of multicellular organisms, such as super-organisms, can indeed be understood to operate as enacting cognition on a collective level, provided that these systems are characterized by high degrees of organizational closure (or *strong organizational closure*, as I have defined it). However, given the difficulty of determining another organism's cognitive states, experience, *Umwelt*, and so on, directly, as well as the added difficultly that arises in cases of living systems whose structures are widely distributed, as with

super-organisms, we must, for the moment, suspend judgement as to whether or not such systems are actually collectively cognitive. Nonetheless, the question of whether or not we can definitively attribute cognition to a super-organism remains as much of an issue as it does for any other living system, and so the question now becomes one of utility—what can a concept of collective cognition do for us in our philosophical and scientific thinking?

I propose that the concept of *collective cognition* can service a new heuristic device for cognitive science, as the concept may help us to better understand both the emergent behaviours of higher-level living systems, such as groups of organisms, as well as the concept of embodied cognition more generally. Moreover, while the insect super-organisms may represent the most compelling possibilities of group-level cognition, nothing appears to rule out the possibility that certain other groups of organisms, and perhaps even whole ecosystems, might also be understood through the notion of collective cognition once we better understand their patterns of organization (consider, for example, the incredible coordination of a flock of starlings, or the astonishing evasive manoeuvres of certain shoals of fish). However, perhaps even more interesting still is the idea that the earth itself may also be understood to exhibit some degree of organizational closure (Lovelock, 1979), and so there may even be some reason to think of the earth's biosphere as a cognitive system.

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