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The loneliness of the enactive cell: Towards a bio-enactive framework

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Abstract

The enactive turn in cognitive science fundamentally changes how questions about experience and behaviour are addressed. We propose that there exists a suite of core concepts within enaction that are suited to the characterisation of many kinds of intentional subjects, including and especially animals, plants, collectivities and artefacts. We summarise some basic concerns of enactive theory and show how the common illustration of the single cell ascending a chemotactic gradient serves as a focus point for discussion of important topics such as identity, perspective, value, agency and life-mind continuity. We also highlight two important deficits of this example: the cell is ahistorical and asocial. Historicity and sociality are defining characteristics of living beings and are addressed within enactive theory by the concepts of structural coupling and participatory sense-making, respectively. This strongly biological framework is to be distinguished from scientific psychology which is, we argue, necessarily anthropomorphic. We propose a constrained bio-enactive framework that remains true to its biological foundations and that would allow us to negotiate consensus-based understanding in contested domains, where incompatible value systems enacted by competing systems are in conflict. A consensual 'we' is, we contend, a matter of negotiation, not of fixed essence. A bio-enactive framework may serve as a jumping off point for consensus-based discussion within contested domains.

Keyword

Enaction, Biosemiotics, Participatory sense-making, structural coupling

1 Introduction

The enactive turn in cognitive science represents an attempt to fundamentally alter the manner in which questions about experience and behaviour are addressed (Froese & Di Paolo, 2011; McGann, De Jaegher, & Di Paolo, 2013). Viewed in that light, it may represent something of a return to the suite of concerns that gave rise to the scientific field of psychology in the latter half of the 19th Century. As one element of the 4E set of approaches to cognition (cognition as Embodied, Embedded, Extended and Enacted), it is rapidly becoming an integral part of a major thrust within cognitive science (Menary, 2010; Barrett, 2015). Each of these four strands within contemporary approaches has its own legacy and motivation, but there are very many overlapping concerns, for example, in recognising the constitutive role of the body, the environment and the other as we seek to understand the organism and its behaviour. As a result, it is easy to see enactivism as one among several related correctives to psychological theory, serving to nudge the field from an overemphasis on abstract reason and the intellect, towards a more thorough engagement with the business of sensing, perceiving and experiencing.

But there are reasons to resist this assimilation of enaction, in particular, to the tradition of psychology. Enactive theory has a strongly biological foundation, and from the outset, it sought to provide a novel vocabulary for understanding the processes of the living at multiple levels, from the individual cell to society, and, we venture to add, to the whole of the biosphere (Maturana & Varela, 1987; Froese & Di Paolo, 2011). It underpins accounts of agentive behaviour for many different kinds of agents, and it provides a technical language for discussing the perspective of a system on its world, without singling out the individual human person as the central, prototypical or only system of interest. Psychological theory, in contrast, has always

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started with the individual singular human person as its centre of reference, and as it has ventured beyond this, for example, in studies of animal cognition, it is the categories and divisions of human psychology, such as sensation, perception, memory, attention, etc., that have been brought to bear. Of course, the further one goes from the human centre, the harder it becomes to use such concepts with any confidence.

The question of the extent to which one's account of behaviour is developed in reliance upon a specifically human and individualist centre of reference needs to be explicitly addressed as behavioural studies turn to such topics as animal (Kube & Zhang, 1993) or plant cognition (Garzón & Keijzer, 2011), the behaviour of collectives (Vicsek & Zafeiris, 2012) or the relevance of the notion of cognition to artificial systems (Parisi & Petrosino, 2010). It is by no means clear that individual human experience provides the most appropriate terms in which to address cognition that is not human, or behaviour that is collective (Barrett, 2015). For example, what concepts should we employ as we seek to understand plant nutation, which is the slow movement through which a pea plant finds a support to wrap its growing tendrils around? If we observe a time-lapse video of nutation, we see the tendrils of the plant describe ever larger circles until they make contact with a climbable surface. We could describe this as perceptually guided search behaviour, but this seems like an inappropriately anthropocentric view of a pea plant. Within the enactive framework, however, the activity can readily be interpreted as sense-making, with due regard to its origin in the specifically plant-like form of organisation we are observing.

But the vocabulary of psychology is not easy to get away from. As we explore the space of autonomous artefacts, or as we approach animal, plant or collective behaviour which we wish to understand, the grab bag of concepts including sensing, perceiving, deliberating, planning, attending and remembering may appear indispensable. They certainly seem to be necessary elements in our vocabulary for interpreting our own being, even if wielding them is a continuous challenge. It seems natural then to apply them as we seek to interpret behaviour rooted in other kinds of subjectivities. But here we must recognise a fundamental difference in the overall goals of the enactive and the psychological frameworks, at least if we take contemporary cognitive psychology as the prime representative of the scientific field.[1] This difference is frequently glossed over, because it raises serious issues about the nature of scientific explanation. To quote Stewart, Gapenne, and Di Paolo (2010):

> It should be clear, but I state it here explicitly, that the paradigm of enaction is ontologically nonobjectivist—or to put it more positively, radically constructivist. "The world," as it can be diversely known by living organisms from bacteria to contemporary humans, is actually brought about, "enacted," by the cognitive organism itself (Stewart et al., 2010, p. 27).

Where contemporary psychology seeks to position itself within the sciences that seek to establish a strongly objective description of a single mind-independent world, the enactive position seeks to relate subjectivities of many kinds to lived worlds of many kinds, with the additional constraint of self-conscious recognition of one's own perspective in framing any observation. This tension runs through the contemporary enactive literature, and it may constitute a significant barrier to the deployment of enactive concepts. In our view, the integration of a non-objectivist, constructivist, framework into the broader domain of science is very much work in progress, requiring the development of appropriate ways to frame empirical inquiry. In this article, we will try to contribute to this integration by identifying a core suite of related concepts at the heart of enactive theory that together provide a non-anthropocentric arsenal that can be brought to bear on subject∼world[2] relations generally, without reliance on psychological framing. We call this restricted subset of enactive theory a *bio-enactive* framework, and we suggest that the term might usefully help to instil awareness of the fundamental distinction between enactive and objectivist frameworks. Enactive theory has much to offer many disciplines, and it may be useful or necessary, in some cases, to combine enactive concepts with received psychological concepts. To do so is to adopt a specific view of subject∼world relations *in that instance*. To take a well-developed example, the sensory-motor correspondence theory of vision, which shares many core concerns of enactive accounts, is concerned with understanding a specific subject∼world relation (O'Regan & Noë, 2001; Noë, 2004). Any insights from such an approach must admit a comparison with received theories of perception, and so it must necessarily employ concepts familiar from perceptual psychology.

If one adopts an objectivist stance with respect to minds, brains and behaviour, there arises a crisp set of distinctions between explanatory domains that has become embedded in many institutions. Autonomy and agency are allocated to the psychological domain, which is co-extensive with the individual person, or, frequently, simply their brain. Social phenomena are then identified as those processes that arise in the interaction between these individual agents. The human and social sciences are distinct from the domain of culture (usually at some distance from the natural sciences), while the natural sciences flesh out our accounts in the mind-independent space. If this broad brush picture of scientific specialisation is accepted, one of the greatest hopes for the psychological and social sciences (collectively, perhaps, the human sciences) is to provide an account of human nature.

In contrast to this, we concern ourselves in this paper with a strongly biologically grounded form of enactive theory, which we situate with respect to a small set of central concepts. In resisting the jump to psychologism and to claims about human universals, human cognition or human minds, we hope to hold fast to the biological and Buddhist origins of enactive theory (Varela, Thompson, & Rosch, 1991) and to finesse legacy boundary issues with psychology (Aizawa, 2014). We recognise the urgency with which researchers seek to generalise from enactive insights to classical debates within psychologically framed cognitive science, but we argue for a pragmatic need to demarcate a theoretical boundary prior to any articulation of a subject~object split. This boundary should provide the ontological light touch, especially with respect to subjecthood and agency, which is necessary if we are to remain fluid as we move towards the generation of bounded consensus within contested domains (Cummins, 2014a, 2014b; Latour, 2013).

We situate our discussion with respect to a specific body of literature, bookended approximately by the 1991 book The Embodied Mind (Varela et al., 1991) and the 2010 collection Enaction (Stewart et al., 2010), and so the core concepts we will deal with are those typically associated with autopoietic enaction, or mind-and-life continuity. After a little historical triangulation, we tease out the most frequently employed example within this literature, that of a single cell chemotactically ascending a chemical gradient. This example allows framing of many of the central concepts of enaction, including autonomy, sense-making, value, perspectivalism, reflective self-recognition, agency and life-mind continuity, and it is thus an invaluable reference point. The cell of this story critically lacks two features though: it is ahistorical and asocial. The stark individualism of the cell, and the absence of a mosaic of interconnectedness that is the hallmark of the living, run the risk of being misinterpreted within an objectivist account (Torrance, 2009).

Based on the key reference points of the 'enactive cell', considered together with the essential historicity and sociality of life, we argue for the cautious delineation of a *bio-enactive framework* as a starting point for consensus-based discussion in domains in which subjectivities and their values must be negotiated. The framework we argue for resists the unreflective reliance on any boundary between a reified mind and world. Specific discussions, for specific purposes, will necessitate going beyond this wilful constraint, which is why we suggest naming the framework explicitly, so that it can best serve as a grounding for discussion. In this manner, the constructivist character of enactive theory may nevertheless contribute positively to vexed arguments in diverse fields in which the perspectives of different kinds of subjects must be confronted, including the sciences, politics and their many entanglements.

2 Situating a discussion of enaction

Although the term 'enaction' was first introduced into the cognitive sciences by Jerome Bruner (1964), it has since been appropriated by a fecund tradition which is conventionally understood to begin with The Embodied Mind (Varela et al., 1991). This book was an audacious attempt to introduce into a scientific discourse various insights about the nature of experience and the subject~object relation that arose within phenomenological and especially Buddhist epistemological traditions. All three of the authors were well versed in both Buddhism, considered as a framework for understanding experience in the first person, and in classical cognitive science, and they went to some pains to situate their contribution with respect to the disciplines they took to be constitutive of the cognitive sciences: neuroscience, artificial intelligence, linguistics, philosophy and cognitive psychology. In the view put forward (tentatively and incompletely), the psychological subject was largely undermined and argued to be a non-unified entity. Cognition was recast as embodied action; the relationship between subject and object was seen as arising in a dynamic process of sense-making, and all such sense-making was understood as tied to the continuous lived history of coupling between subjects and worlds. A strict distinction between subject and world was robustly rejected in favour of a strongly Buddhist sense of groundlessness, and the explanatory domain addressed by the enactive view extended ambitiously from the biological, through the psychological, cultural, social and ecological.

Before the 1991 book, there was a collaboration between Varela and Humberto Maturana, in which they articulated an influential theory of the basic nature of life and the living, known as 'autopoiesis' (Maturana & Varela, 1987; Maturana & Varela, 1991). The prototypical autopoietic system is the single living cell, a theme replayed with endless variations in the ensuing literature, even as the link to autopoiesis itself weakened to the point of breaking. Slightly more formally, an autopoietic system refers to a suite of interdependent processes of generation, transformation and destruction of components, whereby these processes continuously regenerate and sustain themselves as an individuated dynamic entity that engages in regulated energetic exchange with its surrounding environment. In the strict sense, this definition pertains only to individual cells, and it further insists that the suite of processes generate its own boundary, the membrane, separating the component processes from their surround, and that the components taking part in the system be generated by the system. This body of work represents one among several attempts to arrive at a principled account that can distinguish the normative, self-maintaining and self-referential processes of life from other complex phenomena (Schrödinger, 1944; Kauffman, 2000; Rosen, 2000; Deacon, 2011; Collier & Hooker, 1999; Juarrero, 1999). Space prohibits a full account of other significant contributions from cybernetics (Wiener, 1961) and general systems theory (Von Bertalanffy, 1973), which together have provided many formal elements within enactive theory.

Tracing the influence of the 1991 book, the term enaction has become associated with several slightly different undertakings. It is sometimes (we feel inappropriately) applied to the theory of sensorimotor correspondence of O'Regan and Noë (2001). As a theory of perception (albeit as a goal directed activity) this is relevant to, but far more circumscribed than the bio-enactive framework we seek to characterise. It is a useful landmark, however, as it serves as a worked example of how enactive concerns can, when warranted, be integrated within individualist and psychological approaches to the subject. Likewise, some recent yet influential contributions by Chemero (2011) and Hutto and Myin (2013) constitute significant extensions of the enactive canon, but they introduce concerns beyond those we wish to engage with here. Instead we focus on the strongly biological antecedents, sometimes referred to as mind-and-life continuity (Thompson, 2007) or autopoietic enaction (Weber & Varela, 2002; Barandiaran, Di Paolo, & Rohde, 2009; Froese & Di Paolo, 2011). Caution is warranted here, as the 1991 book did not, in fact, reference or employ the term autopoiesis, and the degree to which the strong definition of autopoiesis is considered relevant differs greatly among researchers.

One very important historical antecedent that needs mention is the biosemiotic work originating with Jacob Von Uexküll (Von Uexküll, 1992; Favareau, 2007). A central insight of this tradition is that the world a living being encounters is not a separate, detached, alien proposition, but it arises in terms articulated by the biological structure, the capacity for discrimination and the ability to act, that are rooted in the embodied form of the animal. By way of example, Von Uexküll points out that animals such as fish and mammals that are in possession of orthogonal semi-circular canals as part of a vestibular system, will encounter three dimensional space in a manner quite unlike those of animals without. He describes how the local domain of phenomenal experience arises as a function of the capacity for sensation and action of the animal:

> We no longer regard animals as mere machines, but as subjects whose essential activity consists of perceiving and acting. We thus unlock the gates that lead to other realms, for all that a subject perceives becomes his perceptual world and all that he does, his effector world. Perceptual and effector worlds together form a closed unit, the Umwelt. (von Uexküll, 1992, p. 320).

Within both the enactive and the biosemiotic lineages, a distinction is drawn between the entirety of the surrounding physical environment of an organism (described, e.g. in terms of spatial distribution about the organism), and those aspects of the environment that are of relevance to the survival, health and action of the organism. The latter, more circumscribed, domain is sometimes (loosely) called the Umwelt, the milieu or, if appropriate care is taken, the environment of the organism. Your 'physical' (spatially delimited) environment includes many kinds of electromagnetic radiation, such as microwaves, radio waves, etc., to which your body is entirely insensitive (at values typical of terrestrial exposure), and these do not form part of your milieu, while electromagnetic radiation in the visible range has a manifest influence upon your experience, your behaviour, your enjoyment at the cinema and your ability to survive. The milieu, so circumscribed, is defined with reference to the structure and activity of the organism. Its extent and composition are a function of the capacity of the organism to make distinctions in and to act on its surround. Organism and milieu thus form a mutually-specifying complementary pair, and the milieu should not be thought of as having any independent kind of existence or essence.

Within the enactive tradition as we have outlined it, one illustrative example is frequently invoked: the description of the manner in which a single celled bacterium moves up a sugar gradient. The amount of detail provided when presenting this example varies from author to author, and the apparent purposes for which the description is provided likewise seem to vary greatly. This example is presented, for example in Maturana and Varela (1987, p. 148/149), Thompson (2007, p. 74), Barandiaran et al. (2009), Froese and Di Paolo (2011), Egbert, Barandiaran, and Di Paolo (2010) and many more. We will present a more-or-less typical example of such an account below, containing the main points usually included in the description.

Our contention herein is that this example is not best understood as a set of facts about a bacterium. This story is better understood as a myth, which we mean in an entirely positive sense as a story of reference that provides structures and elements that serve to support and guide thinking. In the case of the cell, it allows us to understand in what manner there is a continuity between life and mind, it allows us to tease out issues pertaining to the organism~milieu relationship, the difference between milieu and physical environment, the nature and degree of autonomy a system can exhibit and the relation between autonomy and purposes. However, while the story of the cell allows enactive researchers to succinctly crystallise the core themes of enactivism, it is equally important for what it omits, namely sociality and historicity.

3 The myth of the cell

In considering the bacterium at the centre of the myth, there are three players: the organism, its milieu and the observer. Crucially, we will contrast the perspectives of a notionally omniscient observer with that of the cell itself. We assume that there is a nutrient source, say a glucose reservoir, somewhere not too far from the cell. Glucose diffuses throughout the ambient medium, creating a concentration gradient that points directly towards the source itself. The glucose is essential for the metabolism of the cell, and within the myth, it is the only external requirement for metabolism, and so the bacterium will do well if it is capable of detecting the gradient and swimming up it towards the sweet source. We can provide an account of how it is that the bacterium manages to approach the nutrient source. That account is couched entirely in mechanistic terms. But the outcome of the mechanism is something quite un-mechanical, and can be interpreted in several ways.

The bacterium has a bunch of whip-like tails called flagellae. They move in two distinct modes. In the one mode, each flagellum lashes around independently of all the others. Because there are several of them, this produces essentially random net movement, and the resulting motion is often described as ‘tumbling’. In the other mode, all the flagellae move together in a coordinated fashion, twisting like a corkscrew and producing net movement along a straight-line trajectory. The bacterium switches probabilistically between the two modes, and the probability of switching from one mode to the other depends upon where the bacterium has been recently. We assume that the cell has some means of registering the ambient glucose concentration in the location in which it presently finds itself. This requires the simplest possible ‘sensory’ device in the form of a very simple receptor in the membrane of the cell. Because it is in motion, a simple temporal subtraction of two successive readings of the ambient concentration will suffice to provide information about the local glucose gradient. If the current reading is greater than the previous reading, the cell is headed up the gradient, otherwise it is getting further from the source. (Nothing substantial hinges on the distinction between discrete measurement events, as described here, or a continuous integration mechanism, as is biologically more plausible.) Now it suffices that the probability of switching from coordinated motion to tumbling motion is increased if the most recent evidence suggests that the cell is getting further away from the source. This simple linkage of a parameter influencing net movement to the detection of ambient information is all that is needed to allow the cell to approach, on average, the metabolically important glucose source. A similar story could be told about avoiding a localised toxin, by raising the probability of switching from coordinated motion to tumbling motion if a recent increase in toxin concentration were detected.

This then is the myth of the cell. We now consider some of the purposes with which this example is recounted, sometimes with a wealth of microbiological detail, and sometimes, as here, in bare bones fashion. These points are well known from the enactive literature and will only be summarised here, but together they show how useful this single example has been in elaborating the core elements of the enactive account.

3.1 Autonomy

The cell is presented as a self-contained entity, bounded by a membrane and discriminable from a background. The metabolic processes that constitute the cell form a dynamic identity, preserved through its own actions serving its intrinsically generated goals of self-maintenance and survival (Weber & Varela, 2002). We can also draw attention to the distinction between the milieu and the complete physical environment. Although there are problems with trying to be too rigorous in applying the notion of milieu to any specific situation in real life, the myth avoids these issues by paring the milieu down to a minimum: the homogeneous fluid in which the cell swims and its heterogeneous glucose content. In dynamical terms, the cell is a prototype of an autonomous system, by virtue of the fact that we can hope to provide causal accounts of its activity that partition neatly into endogenous processes, making up the cell’s systematic organisation, and exogenous processes, originating in the environment and decoupled from the cell’s inner realm.

3.2 Sense-making

The cell must move to maintain its own integrity as a unitary being in precarious circumstances. Within the myth, the only challenge the cell faces is running out of glucose. Real environments are infinitely more complex and varied. The locomotive activity that serves the continued existence of the cell generates an asymmetric *perspective* in which encounters with the world are inherently valenced that is, they serve or confound the goal of the cell’s continued existence. This self-directed activity is termed sense-making.

3.3 Value

The encounter between the cell and the world gives rise to a single spatial differentiation. This differentiation is intrinsically meaningful from the point of view of the cell, as the distinction it manifests is predicated upon the metabolism of the cell. There is no need to attribute any understanding of itself or of its world to the cell. The significance of the distinction is not an analytical result. Glucose is not inherently meaningful in any cell-independent way. But the single perception/action distinction made by the cell of the myth is necessarily of significance to the cell. The introduction of the notion of value into a formal theory allows for the constrained and disciplined discussion of normative constraints.

3.4 Perspectivalism

Thomas Nagel famously considered the question of what it is like to be a bat, and reached the deflationary conclusion that there is nothing that it is like (for a human) to be a bat (Nagel, 1974). With that he was recognising that the immediate experience of the bat is brought about by bat-like embedding in the world, with bat-like sense organs and bat-like capacities for action. While this argument has merit, his predecessor, Jakob von Uexküll did not shy away from studying the structural characteristics of the organs of sensation that underlie all possible perception for specific organisms, and their associated capacity for effective action. The organisms he considered including the tick, paramecium, crow, chicken, snail, dog, scientist, earthworm and many more (Von Uexküll, 1992). In the myth of the cell, we can pursue the same line of attack, and the simplicity of the situation greatly improves our ability to distinguish between the perspective of an almost omniscient observer (us) and the perspective of the cell. While the observer sees the petri dish, the agar, the bench upon which it sits, the many other bacteria, the room and the world beyond the window, we can, without taking undue metaphysical license, say something about the phenomenal world of the cell. This is not to ascribe any consciousness or spiritual essence to the cell. Rather, in recognising that every organism encounters the world from its own perspective, one can take a leaf from von Uexküll's book and exhaustively list the structural characteristics of the world as it makes itself available to the cell by virtue of the cell's capacity for discrimination and action. Most of the environment the observer sees simply does not exist from the cell's point of view, while the character of the interaction between cell and milieu that is available can be considered in terms either of perception or action (von Uexküll's Merkwelt and Wirkwelt, respectively). In both cases, the simplicity of the relationship between cell and milieu shows us that a single distinction arises. The gradient serves to furnish the cell with a minimally differentiated world, in which *this* direction is distinguishable from *that*. The simplicity of the phenomenal distinction available to the cell short-circuits inevitable objections about the minimal complexity required for sentience, consciousness, or even self-consciousness. In noting the spatial differentiation, we have said all there is to say about the world encountered from the cell's point of view.

3.5 Reflective self-recognition

The perspectivalism encouraged by the enactive framework does not map simply onto a distinction between first and third person points of view.[3] Rather, it admonishes the scientific observer to recognise that their world too, is enacted based on their own embodiment and history, and that there is no 'view from nowhere' or 'God's eye view' to which we can appeal. This reflective turn makes enactive inquiry rather different from sciences of the person that adopt a realist or positivist stance.

3.6 Agency

As sketched above, the cell appears to an external observer to exhibit behaviour that serves its own ends. Climbing the glucose gradient is in the cell's interests and not the interests of anything else. This apparent agency arises, despite the fact that the cell of the myth is more-or-less a mechanism. We say 'more-or-less', because although the business of sensing and moving are treated perfectly mechanically, the myth requires that a lot of prerequisites be in place before any such mechanism can be envisaged. Specifically, the apparently agentive action revealed in the myth depends upon the internal organization of the cell, differentiable from all external processes, and requiring a regulated exchange between organism and surround supported by just the right kind of sensory and effector structures. Weber and Varela (2002) go so far as to insist that the apparent agency does not lie merely in the eye of the beholder, but is the very condition of life itself. Others may demur, but the cell will provide a useful minimal discussion point (Cummins, 2014a).

3.7 Life-mind continuity

This story also serves to illustrate what some take to be one of enactivism's most fundamental and indeed radical theoretical ideas, that there is a deep continuity between life and mind. The general idea behind the thesis is that cognition, or mentality, including subjective phenomenology, is not a uniquely human trait but rather something which exists across the phylogenetic scale. All living organisms are seen to share a key number of organisational properties that licence their interpretation as subjects and that permit discussion of their value-saturated worlds. The cell, in many respects, goes straight to the very core of the thesis and illustrates it in dramatic form. In this case the cell assumes the job of being a representative of all life forms, and the account of the cell becomes a means by which we begin to curate a language that allows us to discuss the phenomenology enacted by systems of many different kinds.

It should be abundantly clear from this brief enumeration that the enactive cell serves a crucial role in the ongoing development of the enactive paradigm. But, insofar as this story as been successful, it also remains a very partial picture in two essential senses. The cell is *ahistorical* and *asocial*, and both facets are needed to recognise the manner in which living beings are interconnected and are incomprehensible without each other. Taken without these caveats, the description of the single cell could be interpreted as an individualist account, rooted in an objectivist framework. The enactive account seeks to effect a shift away from a neurocentric, individualistic psychology with a fixed subject~world split, and towards a mind-life continuity framework in which a value-saturated, intrinsically meaningful world arises for beings of concern whose very identity lies in their continuous becoming. The story of the cell helps here for all the reasons outlined above, but it omits these two crucial features, without which enaction cannot plausibly offer an alternative to the manner in which an objectivist scientific tradition treats of being.

Ahistoricity refers to the fact that we encounter the cell without any past. Neither ontogenesis, nor phylogenesis are described, and so the cell simply appears, goals and all. Removed from its past in this fashion, the goals of the cell appear indistinguishable from the goals of any artefact, that is, imposed by a capricious designer. In the biological domain, however, the embedding of organisms into their environments comes about through developmental and evolutionary processes of reciprocal accommodation and assimilation. When we, as observers, pick out the cell as an distinguishable individual, we are, in many ways, extracting it from its history of interactions.

Asociality refers to the fact that the cell is presented alone, without any dependence on any other organisms. In the myth, its only need is for glucose, and its only actions are those that make sense as the search for glucose. No living being is asocial in this manner. Ahistoricity and asociality are essentially linked, although they have been addressed through different elements in enactive theory, namely structural coupling and participatory sense-making, respectively.

4 Of history and sociality

When enactive theory seeks to bring a common set of core concepts to bear on subject~world relations at diverse levels, from the single cell, through multicellular organisms, to forms of supra-organismic organisation, the language sometimes becomes a little unstable (Maturana & Varela, 1987; Froese & Di Paolo, 2011). Some choose to speak of 'the autopoietic system', even though autopoietic theory is a theory strictly applicable at the cellular level and with reference to chemical interactions alone. Other times talk is of 'systems', 'organisms' or 'unities'. For clarity, we will here speak of organisms, O, and milieu, M, but our discussion is intended to allow widening to include dynamically individuated systems that act agentively at any level.

Figure 1. Hummingbird and flower illustrate the notion of structural coupling.

The organisational unity of O is preserved through the sense-making activities of reciprocal interaction with M. This necessarily leads to coupling between the two ($O \sim M$). Given the manner in which M is defined with respect to its role in the ongoing sense-making activities of O, the two systems are continuously codefining. If, for example, in the process of phylogenesis, O were to acquire the capacity to make a novel discrimination, for example, detecting a specific chemical, this will necessarily lead to a congruent change in the structure of M. O and M are said to be structurally coupled. For biological organisms, structural coupling extends over both ontogeny and phylogeny. Figure 1 shows the exquisite match between the beak of a hummingbird and the trumpet of a flower, illustrating the inextricable intertwining of organism and milieu, in this illustrative example with focus on coupling at the phylogenetic scale. Both bird and flower are strictly uninterpretable without the other. The flower forms part of the bird's milieu and the bird forms part of the flower's.

Along with historicity extending back to the very origin of life, we must also insist that all life forms are social in their very essence. Sociality and historical intertwining and entanglement are fundamental conditions of organismic life itself. The very act of reproduction is, of course, an extreme form of mutual dependence at the heart of the living, and one of the main means by which we distinguish the living from the inert. In sexual reproduction, the diachronic and the synchronic coincide, bringing historicity into collision with sociality. Altricial animals like humans with extensive periods of complete dependence on parental care make this form of mutuality more obvious, but even entirely precocial animals such as turtles or crocodiles who enjoy no such parental investment are of corporeal genesis, *genitum, non factum* (if we may misappropriate a venerable phrase from the Nicene Creed). In reproduction, at the heart of life, we see the inseparability of sociality and historicity.

Nor are 'simpler' organismic forms somehow less deeply entwined within the web of life. Bacteria act collectively, exchanging complex signals, even engaging in deception in pursuit of collective goals (Ben-Jacob, Becker, Shapira, & Levine, 2004; Lyon, 2007). The elaborate eusocial lives of ants and termites were a central example discussed at the start of the 20th Century, as the reality of social relations and institutions came under scrutiny (Sleigh, 2002). A commitment to life-mind continuity requires one to acknowledge that sociality is not only to be found in the human domain but inheres in life itself, beginning already with the single cell organisms that feature so large within enactivism. There cannot be sociality without individual organisms but, unlike what the story of the cell seems to suggest, it seems that without sociality there cannot be any individual organisms. To quote George Herbert Mead:

> It cannot be said that the individuals come first and the community later, for the individuals arise in the very process itself, just as much as the human body or any multicellular form is one in which differentiated cells arise. There has to be a life-process going on in order to have the differentiated cells; in the same way there has to be a social process going on in order that there may be individuals. It is just as true in society as it is in the physiological situation that there could not be the individual if there was not the process of which he is a part (Mead, 1934, p. 185–189).

(Unfortunately, Mead then goes on to single out humans as exceptional, and to insist that only humans have selves. This collapses his account back to a post-enlightenment myth of the rational human agent, acting volitionally, and in independence of his (yes, usually 'his') material and animated context.)

Although structural coupling (historicity) has been part of the core enactive vocabulary since the 1991 book, it was not until 2007 that the core vocabulary was extended to accommodate ongoing reciprocal activity among two or more systems (sociality). The term 'participatory sense-making' was introduced in De Jaegher and Di Paolo (2007) to refer to the manner in which the sense-making activities of one organism become constitutively entangled in the sense-making activities of another, producing a transient superordinate domain with its own autonomy. This novel domain must be seen as enacting its own world, and it will persist or fall apart in dependence on its regulated exchanges with its milieu.

Formally, participatory sense-making represents a straightforward, even obligatory, extension of the basic elements of the enactive framework. In dealing with living beings, from cells up, we are dealing with bounded elements that display a persistent dynamic identity over time, maintained through their sense-making activities in which they engage in regulated exchanges with their surrounds, and thereby constitute themselves as subjects opposed to worlds. As some of the most important constituents of the environment of most living beings are themselves living beings, and frequently conspecifics of similar bodily constitution and physiology, the sense-making activities of any one autonomous being become constitutively entangled in the sense-making activities of many others. Through the historical process of structural coupling, whereby present interactions bear the stamp of past histories of interactions, similarly constituted beings will come to enact meaning in similar ways, and will thus inhabit shared worlds that are saturated with meaning in similar ways for each individual. This general account seems to apply to all forms of life, with no exceptions. It is certainly not stamped with the mark of anthropocentrism. In particular, it makes no reference to the specific form of coupled interaction that arises with language and languaging, which will be necessary if the account is to be extended to human sense-making and the development of a shared human world in which histories can be narrated, and a common future can be conceived. The bio-enactive account we are delineating, in its formal statements, is not anthropocentric, individualist, or internalist.

5 Negotiating subjectivities

To what ends shall we then turn this intellectual heritage and its densely interconnected suite of concepts? Which constituencies will the enactive vocabulary enable, or even liberate? Balanced precariously between philosophy, biology and cognitive science, the enactive turn raises issues of consequence to anyone working within the domain of the animate, and it promises to provide means for addressing multiple subjectivities, multiple perspectives and multiple scales of value, even and perhaps especially when these are contested and in competition. In its wholehearted embracing of a form of radical constructivism, it will sit uneasy within any positivist scientific framework. With its insistence on reflective self-recognition, it challenges theorists to recognize their own inextricable involvement in the worlds they articulate, bringing an ethical charge to enactive theory that is foreign to much of contemporary science.

It is in recognition of these challenges that we propose to articulate the bio-enactive framework, with just those concepts at its core that can be potentially employed in characterising many different kinds of subject~world relations, whether those subjects be individual or collective, human, animal, plant or artificial. The bio-enactive framework we propose leans heavily on those central concepts that can be illustrated with the myth of the chemotactically navigating cell, with the addition of the important extensions of structural coupling and participatory sense-making. In selecting from the enactive literature and its rich suite of concepts in this fashion, we have consciously opted to employ a bio-semiotic approach towards the structure of experience, and we have eschewed the more familiar reliance on the phenomenological tradition and the use of first-person descriptions of experience (Favareau, 2007). This seems to us to be an important way of circumscribing a set of concepts that can properly address the many and varied forms of subjectivity outlined above, without introducing unwarranted anthropocentric assumptions (De Jesus, 2015).

We have sought to argue that enactive theory is not a corrective for scientific psychology. Scientific psychology is intrinsically concerned with developing accounts of autonomous discrete human individual. This is important business. Enaction may contribute to this, as we see, for example, in the theory of sensorimotor correspondence (O'Regan & Noë, 2001; Noë, 2004). But having available to us a core suite of concepts carefully selected to avoid anthropocentric assumptions should enable the construction of accounts for subjects other than the psychological subject. In our own work, this vocabulary has enabled the formal acknowledgement of collective intentionality as manifested in the synchronised speaking and gesturing found in practices of prayer, protest, and in enacting identity among sports fans (Cummins, 2013, 2014b). For those who seek to understand behaviour of animals quite unlike humans in their embodied forms, or who want to extend the notion of cognition to plants, artefacts or collectivities of any sort, it provides a rich, biologically grounded, starting point that can potentially avoid the taint of anthropocentrism (Barrett, 2015).

Subjectivities are not enumerable entities. Each cell, each organism, each collective, each blade of grass, flock of birds, choir, team, business, nation and mob constitutes a form of organisation that can be viewed as the enactment of an identity, and thus allows recognition of value as it arises for and from the perspective of the system itself, together with system-external views. This is a language with which the relation between an organ and a body, or a congregation and an ambient society can be discussed, but it is a cautious language. The notional boundaries between the person and their world, or between one species and the rest of the biosphere appear in this light to be specific territorial limits among uncountably many others, and the presumed reference of the personal pronouns 'I' and 'we' will shift fluidly from one context to another, resisting positivist fixation.

And so we tentatively suggest using the term 'bio-enactive' framework for a starting point and an attitude, from which specific approaches to matters of collective concern are developed. We choose not to use the term autopoietic enactivism, partly because this has become overlaid with multiple derived and shifting senses, but also because the biological and groundless (in the Buddhist sense) foundation of the 1991 Embodied Mind did not lean on this, and it is one significant landmark we wish to reference. Use of this term will also allow extension of enactive thinking into domains within which specific splits between subject and object are assumed, without introducing further terminological overlap. The bio-enactive framework then is not an improved form of psychology. It is a framework within which we can find our place among the processes of life.

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Notes

1. Psychology has always been a diverse field. Many of its goals are frankly utilitarian and at some remove from science. Contemporary cognitive psychology, however, is strongly grounded in classical objectivist approaches to science.
2. We use the tilde notation introduced in Kelso and Engstrøm (2006) to indicate a complementary pair, where each term serves to co-define the other, as in subject~world, good~evil or mental~physical.
3. The manner in which first person phenomenology, as developed within the Husserlian tradition, is relevant to enactivism is an area of ongoing debate (De Jesus, 2015). We restrict ourselves here to the more constrained approach of biosemiotics, in which structural characteristics of the experience of one being, X, are considered as they might be understood by another being, Y.

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