A Strong Continuity of Life and Mind:
The Free Energy Framework, Predictive Processing, and Ecological Psychology

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Abstract/Lay Summary

Located at the intersection of philosophy of cognitive science and philosophy of biology, this thesis aims to provide a novel approach to understanding the strong continuity between life and mind. This thesis applies the Free Energy Framework, predictive processing and the conceptual apparatus from ecological psychology to reveal different manners in which the organizational processes and principles underlying life have been enriched so as to result in cognitive processes. By using these anticipatory cognitive frameworks this thesis unveils different forms of cognition at work in surprising places and considers how such expressions of cognition are ultimately driven by various forms of environmental complexity. Importing the concepts of affordances, environmental information and perceptual medium from ecological psychology into predictive processing and the Free Energy Framework, an empirically grounded account of cognition as an anticipatory process that allows living systems to adapt to various degrees of uncertainty in their environments at distinct and yet overlapping timescales is argued for. In doing so, this thesis attempts to identify both the explanatory limits of ecological coupling accounts of perception and action, and the possible environmental conditions under which the predictive brain evolved from its decentralized non-neural predecessors as a solution to uncertainty. In contributing to a novel approach to constraining the mind, the various concepts deployed in both philosophy and cognitive science are sharpened, furthering the current debate on what cognition is and how it is related to life.

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Introduction

> *"Nevertheless, the difference in mind between man and the higher animals, great as it is, certainly is one of degree and not of kind"* (Charles Darwin, 1871 p. 85).

The continuity between the cognitive faculties of 'higher' animals (e.g., apes, monkeys, canines, etc.) and those of human animals is something that most cognitive scientists today would not find contentious. However, one thing that remains unclear and certainly debateable is the point(s) at which mind (a term which will be henceforth interchangeably used with "cognition") begins to emerge in the evolutionary history of living systems and just how far 'downwards' the continuity of mind reaches in describing the capacities of lesser complex organisms. Although any current answer to this question will be somewhat speculative in nature, there are certainly better and worse speculative answers that can be arrived at. This thesis does not aim to provide any final say on the question but aims less ambitiously to provide a systematic manner of thinking about continuity of life and mind. More specifically, the primary question which this thesis addresses is:

> What kind of insights do the Free Energy Framework, predictive processing and ecological psychological collectively offer about the strong continuity of life and mind?

To understand the nature of this question, let us proceed by looking at a series of more general questions and establishing some provisional characterizations of life and mind over the course of this introduction. The hope is that analysing these more general questions and laying down provisional manners of thinking about “life” and “cognition” will lead us back to the primary question with a better understanding of what it is asking and what is at stake.

The aim of this introduction is to provide a tour of the theories and theoretical frameworks that will be deployed throughout the thesis in investigating the relation between life and mind. A few caveats however before proceeding. This thesis is naturalist in its approach to doing philosophy. Rather than leaning on *a priori* conceptual analysis, the central manner in which the primary question will be investigated throughout will be supported with evidence from scientific disciplines – especially biology and cognitive science. This is not to downplay the importance that sharpening concepts will play in this thesis, but it is to say that it is empirically and scientifically informed conceptual analysis that will drive this investigation into strong life-mind continuity. With this in mind, it should be noted that the provisional characterizations provided below are not meant to be definitions in the sense of providing necessary and sufficient conditions. They are merely useful characterizations that will be deployed as starting points in the investigation of the primary question and other questions which may fall out of it. Over the course of this thesis these characterizations will be sharpened and revised in light of both the empirical evidence considered and the insights provided by the frameworks and theories that will be put to use.

0.1 Life-mind continuity

How is life related to mind? One general manner of answering this question, the manner that is central to this thesis, takes the form of what has been called the *life-mind continuity thesis* (LMC) (Godfrey-Smith, 1996). LMC in its least controversial form suggests only that cognition requires life. In other words, wherever there is mind, there is life and yet the converse is not true. In contrast to this position, a stronger interpretation of LMC suggests that cognition is an enriched version of the same organizational principles constitutive of life. These two versions of LMC have been referred to respectively as the "weak continuity thesis" and the "strong continuity thesis" (Godfrey-Smith, 1996). Let's consider them in a little more detail.

If the weak continuity thesis is true, then cognition at base turns out to be a kind of biological process.[1] However, there is no commitment to the existence of (or specifications of) underlying principles or properties which life and cognition share. Weak continuity is something which sits well with our intuitions and folk concepts of cognition and life. Humans, along with some other animals engage in cognitively driven behaviour but rocks don't. One possible source of the intuitive force behind weak continuity may be based upon the fact that most of the agents that we uncontroversially recognize as cognizers and interact with on a day to day basis are living.[2] Another motivation in favour of weak continuity arises when thinking

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[1] This is interesting at least for two reasons. Firstly, it goes against a dominant theoretical current in the history of AI and computational modelling, a current that sees cognitive systems as something which may be investigated entirely independently from living systems. Secondly, weak continuity challenges the somewhat orthodox notion of multiple realizability (i.e., that mental states and processes may be instantiated in a multiplicity of different physical structures) that accompanies functionalism in the philosophy of mind (see Godfrey-Smith (1996,2002). Cognition, if weak continuity is true, may require very particular (biological) substrates to be in place in order to be realized.

[2] Although current cognitive robotics has recreated particular aspects of cognitive systems, that they have recreated full blown cognitive systems that are able to perform more than highly simplified tasks in well-defined (non-natural) environments is a more tendentious claim.

about what it is that cognition does for those living things that deploy it. For example, if cognition is understood as a toolkit of various capacities, the evolution of which occurred as a result of the various fitness related benefits that such capacities bestowed on living things (Godfrey-Smith, 1996), then weak continuity falls out of this evolutionary understanding of what cognition does (more will be said about this functionalist view of cognition below in Section 0.1. Amongst the proponents of weak continuity have been most notably John Dewey (1929) and Peter Godfrey-Smith (1996,2002).

In contrast, strong continuity is more than the claim that life is necessary for cognition. It is stronger than the weak continuity thesis in that it specifies (although abstractly) how life and mind are related: cognition is an enrichment of organizational principles and properties definitive of life. The process of cognition somehow outstrips the process of living and yet both are governed by (and thus related by) the same organizational principle(s). Hence, life and cognition may be understood to be different in form but not different in kind or, in other words, “mind is literally life-*like*” (Godfrey-Smith, 1994, p. 83). Amongst the notable proponents of strong continuity have been Aristotle (1907), Herbert Spencer (1885), and Charles Darwin (1871). Both weak and strong continuity leave the possibility open that life and mind, although not identical (numerically or otherwise) might very well be co-emerging processes (i.e., where there is life there is mind and where there is mind there is life). Let it be stressed, however, as I am interpreting strong continuity, it is not built into the definition that life entails mind; rather, strong continuity makes the claim that cognition builds upon life without taking a stand on whether or not the process of life which cognition builds upon is imbued with properties specific to cognition. As such, it is consistent with strong continuity to hold that perhaps most life is minded and that which is not fails to instantiate those enriched patterns of organization specific to cognition.

What might motivate the strong continuity thesis? One straightforward motivation may come from considering the homeostatic resilience of living organisms. Being alive implies being able to return to a limited range of homeostatic states (e.g., metabolic-related, temperature-related, osmotic-related, etc.) and all living organisms are equipped with various manners of avoiding their own systemic dissipation via homeostatic regulatory mechanisms (allostatic change, enabling the return of homeostasis). Under the assumption that various cognitive capacities have evolved because they allowed living systems to cope with selective pressures in their surrounds (Godfrey-Smith, 1996), and given that homeostatic regulatory mechanisms are the most minimal conditions for coping with selective pressures (deprive any organism of the continued functioning of regulatory mechanisms and you soon deprive it of life), then one might reason that cognitive capacities are enriched versions of living processes because they are enriched versions of such regulatory mechanisms. The thought is that because such homeostatic regulatory mechanisms were already in place, rather than having to ‘start from scratch’, evolution by natural selection could enlist and improve upon these mechanisms, providing a manner for living systems to respond effectively to the dynamic pressures of their environments. Importantly, with enriched regulatory mechanisms such living systems could branch out environmentally, slowly coming to occupy and create new niches with different forms of selection pressures that their continuously evolving specialisations were adapted to.

It is with this kind of rationale that some theorists have argued that these homeostatically enriched specialisations may have minimally taken the form “meta-metabolic functions” (Moreno & Etxeberria, 2005) before reaching the status of cognition. Such meta-metabolic functions are characterized by fast and flexible metabolically decoupled internal dynamics which play the role of exerting (behavioural) control over slower environmentally coupled metabolic-based processes. Importantly, metabolically decoupled internal dynamics support flexible adaptive coping with the environment in ways that ultimately bring about the conditions for continued metabolic functioning. Thus, meta-metabolic functions are “meta” in the sense that they regulate metabolic regulatory systems. While some theorists have postulated that such meta-metabolic functioning required the evolution of nervous systems before getting a foothold (Moreno & Etxeberria, 2005) others have argued that nervous systems were merely an augmentation of regulatory capacities that were already in place in non-neuronal organisms (van Duijn, Keijzer & Franken, 2006; Lyon, 2006; Bitbol & Luigi, 2004). Both of these manners of arguing for where meta-metabolic functions arise may be seen as representative of the strong life-mind continuity thesis in virtue of their identifying empirically defensible manners in which the enrichment of homeostatic regulatory mechanisms could have resulted in *bona fide* cognitive processes (a rough and ready working characterization of cognition will be provided below).

Lastly, there is an even stronger interpretation of the LMC. The entailment thesis states that where there is life, there is mind (and the converse also being the case).[3] In contrast to both weak and strong life-mind continuity which hold that life is necessary for mind, the entailment thesis holds that life is both necessary and sufficient for mind. If entailment is true, then life and mind are co-emerging processes and complex modes of mind and life build upon lesser complex modes of the same. In other words, unlike strong continuity which sees the role of enrichment as an "adding to" the processes fundamental to life, entailment sees enrichment as an "adding to" cognitive (and life) processes from the start to arrive at ever more complex modes of cognitive (and life) processes. Notable proponents of the entailment thesis have included Hans Jonas (1966) and Maturana & Varela, (1980).

The entailment thesis is often motivated by autopoetic theory (Maturana & Varela, 1980), which holds that all living systems—from bodily cells to blue whales—are autopoetic systems. Broadly, autopoetic systems are those which both adaptively respond to their environmental dynamics and continue to actively produce

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[3] Autopoietic theories of mind and life have used "strong life-mind continuity" and/or the "deep continuity of life and mind" to refer to what I am here calling the entailment thesis. See section 2.0 of chapter 1 for an example. For readings of the strong life-mind continuity thesis that are consistent with the manner in which I will continue to use it see Stillwaggon (2005) and Wheeler (2011).

themselves and their systemic boundaries (Maturana & Varela, (1980). Cognition includes in its most minimal sense what is called “sense-making” (i.e., norm and significance driven behaviour) (see Thompson, 2011, p. 42). For example, certain features of a bacterium’s milieu (e.g., glucose gradients) are valuable as food insofar as a bacterium is a glucose metabolizing organism that can climb glucose gradients. It is in virtue of their active sense-making that living systems have a significance-laden perspective on the world, and having this perspective, the thought goes, means that even the simplest living systems’ active exchanges are cognitively driven.[4] As such, autopoetic theorists reason from the claims that all living systems are autopoetic systems *and* that all autopoetic systems are inherently cognitive (i.e., sense makers) to the conclusion that all living systems are inherently cognitive.

This thesis will be primarily concerned with investigating strong life-mind continuity.[5] Its truth will be taken as an assumption – it will not be directly argued for. Over the course of this thesis we will see that the kinds of explanatory frameworks associated with strong continuity turn out to have surprising applications, and to be able to deal with more kinds of cognitive phenomena than we might have thought. Thus, while I do not directly argue for strong continuity, this thesis still does work in making it a plausible position. Given that strong continuity implies weak continuity (Godfrey-Smith, 1996) this thesis will investigate the weak life-mind continuity only indirectly. Strong continuity may be thought of as a determinate of determinable weak continuity. Similarly, the entailment thesis, something which this thesis will be concerned with only marginally, may be thought of as a determinate of determinable strong continuity. Thus, when asking about

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[4] Importantly, sense-making need not entail the kind of intentionality that is distinctive of human cognition (whatever that may be).

[5] This being said, if this thesis succeeds in deploying the Free-energy Framework, predictive processing and ecological psychology to help clarify strong life-mind continuity, then it might indeed make strong life-mind continuity a more tenable thesis.

the relationship between life and mind, there are at least three ways of interpreting LMC (see Figure 1).[6]

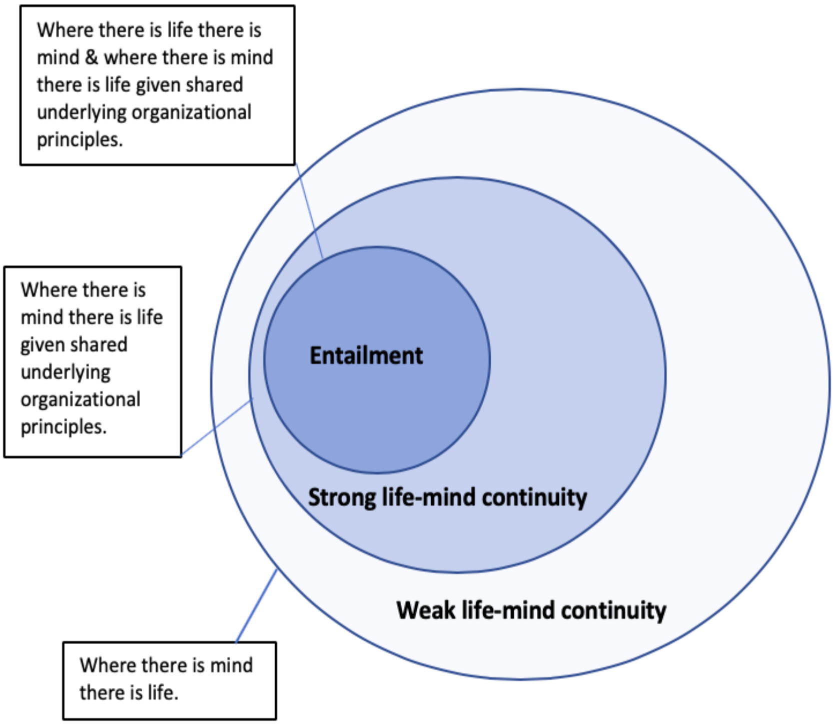

Figure 1

Three interpretations of the life-mind continuity thesis

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[6] I write "at least three" here to make conceptual space for a fourth interpretation of LMC that allows for the possibility that mind needn't require life, but mind is necessary for life. This kind of position would be one that stands in direct opposition to weak continuity which sees life as a necessary condition for mind.

0.2 Characterizations of life and mind

Of course, whether or not any given agent qualifies as being alive and/or a cognizer is dependent upon how we understand the concepts of life and cognition. Currently, there is however little to no consensus in philosophy, biology or cognitive science as to how to define either cognition or life; some theorists even going so far as to doubt the fruitfulness of defining cognition or life to scientific practice (see Bich & Green, 2018 for a case against defining life; see Allen, 2017 for a case against defining cognition). While acknowledging there is controversy here, this thesis will use the following initial characterizations of life and cognition as place holders (not definitions!) in order to approach the question as to how life is related to cognition.[7]

A provisional characterization of life may take the following form:

> Life: an adaptive process by which an open system, in virtue of its metabolic processing, continues to both produce and actively preserve itself as a well-delineated unit despite the precariousness of its environment.[8]

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[7] That some biological sciences are fruitful without using explicit definitions of 'life' is consistent with the fact that other biological sciences (e.g., astrobiology, systems biology, origins of life, etc.) require working definitions. Take for example astrobiology if we want to send a probe to a different planet to search for life there, we must make some assumptions about the kind of thing we are looking for.

[8] One important feature of life which is not included in this characterization of living systems is that of reproduction (Maynard-Smith & Szathmary, 1995). Given that this thesis when analysing LMC does not take the perspective of biological individuals as units of reproduction but rather the perspective of biological individuals as physiological units, reproduction as a feature of living systems will not be focused upon here or in the chapters to come.

Let us briefly analyse this characterization, beginning with the notion of *open systems*. Such systems are those that exchange energy, matter and/or information with their environments. One way of being an open system is to be a system that uses *metabolic processing*. Such processing is characterized by both the harvesting of energy in the form of resources (i.e., anabolism) and the breaking down of that energy for work (i.e., catabolism). The notion of *self-production*, a concept that is both central to autopoetic theory (Maturana & Varela, 1980) and the chemoton model of minimal life (Gánti, 1971/1987) names the circular process that a biological system engages in of (1) reconstructing itself by synthesizing its component elements and (2) bringing about processes which in turn allow it to bring about or maintain those very processes and synthesize the component elements which are fundamental to it. Central to the notion of *active self-preservation* is that the living system is the source of the processes which constitute its own self-preservation. The last of the crucial notions in this first characterization of life are related; the notion of *active self-preservation* is relative to the kinds of *environmental conditions* encountered by a living system. Active self-preservation is a specific manner of actively adapting to the environment. What must necessarily be preserved is a boundary that separates that living system from what it is not. In other words, the process of life requires that a biological system through its own devices (i.e., actively), maintains itself as a distinct unit from the environment in which it is embedded. Living systems remain living when they manage to produce and preserve themselves despite various encounters with integrity challenging environmental dynamics (e.g., temperature and pressure fluctuations, lack of metabolic resources, the presence of predators, the presence of competitors, etc.).

This characterization of life seems to overlap with our folk biological intuitions concerning what kinds of thing are living; everything from bacteria to humans seem to engage in this kind of process; whether or not viruses are living according to this characterization, given that they do not possess their own machinery for metabolism, is less certain; neither rocks nor robots (at least up until now) exhibit life.

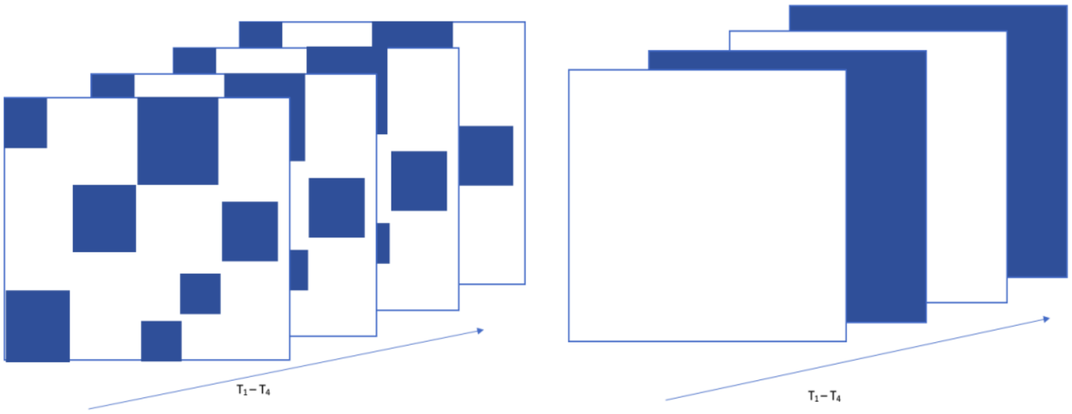
Moving on to a provisional characterization of cognition:

> Cognition: a process by which an agent actively adapts itself to the conditions of its environment through the deployment of different interacting capacities.

Explicit in this very broad brushstroke characterization of cognition is the idea that cognition is not expressed in merely one capacity, but is a process that involves a collection of many capacities (e.g., perception-action, learning, memory, language, decision making, etc.) Importantly, whatever this collection of capacities may turn out to be, this characterization of cognition leaves the possibility open that such capacities may be expressed differently in different systems; they may take various forms using different mechanisms which allow for the kind of adaptation that is relative to both organism-type and the types of precarious environmental conditions encountered. By describing cognition in terms of what cognition *does* or what it is *for* (i.e., it is something which guides adaptive interaction with the environment) this initial characterization falls under the category of a teleofunctional characterization (the prefix "teleo" coming from the Greek *telos* which translates roughly as purpose or aim). Teleofunctional characterizations of a given capacity answer the question *why* that capacity has been selected for over the course of evolutionary timescales (Wright, 1976; Godfrey-Smith, 1996). One such teleofunctional characterization of cognition which is implicit in the provisional characterization of cognition above (and one which will be revisited throughout the course of this thesis) is the environmental complexity thesis (Godfrey-Smith, 1996):

> The environmental complexity thesis (ECT): the function of cognition is to allow organisms to cope with environmental complexity.

Complexity is understood here as heterogeneity or being composed of different (interacting) parts at the same or different times (see Figure 2).



a.

b.

Figure 2

Examples of complexity across two different spatio-temporal scales: in plate a. there is complexity exhibited spatially at each time-step, although it remains the same over time. In plate b., although at each time-step there is no complexity spatially, there is complexity across time.

Cognition is adaptive only when there is both *variability* (i.e., complexity) in the environmentally distal states that are relevant to an organism's survival and *stability* (i.e., highly reliable correlation) between those distal states and the proximal states to which an organism is sensitive.[9] Thus, the claim of ECT is that complex environments were a requirement for cognition.[10] For without the variability in the environmental states that are relevant to an organism, cognition would have not been needed as an adaptive solution that makes use of stability to control complex behaviour.

Whereas environments with more complexity may require cognitive capacities that are themselves more functionally specialized in order to allow for successful adaptation, environments with less complexity may be dealt with using simpler capacities. This kind of *complexity matching* between environmental complexity and cognitive complexity will be a recurring theme in its various guises throughout the chapters that follow. I noted above that ECT was implicit within our initial characterization of cognition. Given that cognition allows a system to actively adapt to environmental conditions, and that actively adapting to environmental conditions is tantamount to dealing with environmental complexity, cognition may therefore––as ECT suggests—be seen as having the function of dealing with environmental complexity. This being said, not all manners in which an organism deals with environmental complexity qualify as cognition (e.g., digestion, respiration, hibernation, etc.). Attempting to identify those manners that do without being overly permissive will be a recurring project of this thesis (see chapters 1, 2, and 3).

The notion of *adaptivity* is a common feature of both the characterizations of life and cognition provided above. Although adaptivity may be understood in a more general manner as the ability of an organism to cope with environmental change,

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[9] According to Godfrey-Smith, (1996) ‘distal’ here need not be construed in terms of spatial distance but may also include behavioural tendencies that are less regular (i.e., dispositional behaviours).

[10] Godfrey-Smith takes ECT and life-mind continuity (of any variety) to be independent theses. Assuming this is correct, it is still possible to use ETC methodologically in order distil a functional notion of cognition that can be used to investigate life-mind continuity. As I hope to show in this thesis, ECT and strong life-mind continuity may be brought together by a particular conception of cognition that sees it geared towards the anticipation and adaptation of living systems to the complexities of their environments.

throughout this thesis I will follow Di Paolo (2005) in using the term more specifically to refer to “a special manner of being tolerant to challenges by actively monitoring perturbations and compensating for their tendencies” (2005, p.9).[11] Whereas adaptivity underlying life may take the form of a system’s monitoring the states that challenge its viability and engaging in active self-preservation (i.e., behaving in ways that directly support continued homeostatic regulation), the kind of adaptivity underlying cognition may be more general; it may take the form of a system’s monitoring the states that challenge non-existential goals and making various types of adjustment to environmental conditions such that those goals are not impeded (e.g., making a good chess move to win the match). Importantly, the processes that are expressive of *active* adaptive processes differ from those expressive of passive adaptive processes in that the former are endogenously generated by the system itself. For instance, a “smart” heat-seeking missile might adaptively preserve itself whilst in flight by avoiding collisions with various obstacles that it encounters which are not its target. However, in this case, such adaptation boils down to a set of non-physiological controlled variables (i.e., variables that are kept in a specific range for the system to function as it was designed to) and response parameters that have been programmed and determined extrinsically to the system (i.e., by an engineer). To say that a living system actively adapts itself to its environment is tantamount to saying that its adaptivity is an expression of the biological autonomy of that system. More will be said about the notion of biological autonomy in chapter 3 but let it suffice for now to understand autonomy as the capacity that a system has to govern its interaction with its environment. Such a system is self-directed in the sense that it is its own organization that determines whether or not and how it adapts to environmental perturbation.[12]

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[11] I will continue to use the term “adaptivity” without taking on all of the commitments of autopoetic theory. My attitude to some of these commitments will become apparent over the course of this thesis.

[12] The notion of “autonomy” that this thesis will help itself to is in line with thermodynamic accounts of self-organizing dissipative systems; such systems, through a process of *energic exchange with their environments*, counter the dissipative effects of random fluctuations, thereby remaining distinct from their environments (see Turner, 1982). Living systems are a subclass of

Let the reader be reminded once more that these characterizations of cognition and life are provisional and will, throughout the course of this thesis, be sharpened in light of various considerations examined in each chapter. This being said, we will now turn to one feature that may be used to not only refine the initial characterizations of cognition and life, but that also motivates the use of the frameworks that will be deployed throughout this thesis.

0.3 Anticipation

Assuming that strong life-mind continuity is correct—as this thesis does-—and that both life and cognition are active adaptive processes—as this thesis does—what can be said about the manner in which cognition contributes to the self-preservation of living systems? More precisely, what is it about cognition that enables living systems to deal with environmental complexity so as to preserve themselves? There are two ways of interpreting this question. On one interpretation, it is a question about the kinds of particular strategies that might be used to navigate challenging environments (e.g., problem solving, learning, perception, sensorimotor coordination, memory etc.). On the other interpretation, this question asks about a possible underlying feature (or features) of all such cognitive strategies. For the purposes of this thesis, it is this second interpretation that I am interested. This thesis, following a long tradition in psychology and cognitive science (Bartlett, 1932; Craik, 1943; Piaget, 1970; Neisser, 1976;

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self-organizing dissipative systems that characteristically direct their own exchange with their environment and hence exhibit autonomy. This notion is importantly distinct from the “autonomy” of traditional autopoietic theory, which denies the fundamental role of system-environment exchange (cf. Godfrey-Smith, 2016).

Drescher, 1991; Arbib, 1992; Grush, 2004; Castelfranchi, 2005; Bar, 2007) takes anticipation as an essential property of cognitive systems.

To see why this is intuitively feasible, consider the following simple thought experiment. Imagine a particular organism, *O*, possessing cognitive capacities that are purely reactive and limited to acting, tactile perception, and learning. Moreover, imagine that *O* inhabits a very simple environment, consisting of empty space, one kind of food source and one kind of predator. Now in order to identify food and nourish itself *O* must move around, touching everything that it comes into contact with. Depending upon the predator population and the abundance of food, this kind of strategy for food identification and nutrient consumption could be a metabolically expensive process over the long run and, more importantly, immediately dangerous. For example, if food was not abundant but predators were, depending on how fast and severe the damage inflicted upon *O* by these predators (and how fast or resilient to damage *O* is), it would be very likely that this purely reactive creature would fail to survive very long, perishing in its attempts to nourish itself. Now imagine a slightly different scenario, where a property of the food, say its porous texture, is a cue for the presence of predators; there is a reliable chemical reaction that causes the food's surface to become porous when exposed to the predator's fresh metabolic waste. Furthermore, imagine that *O* has the capacity to detect and use this textural cue to direct its behaviour. In this case, food with a porous texture is a predictor of the presence of predators. With this simple addition of a textural cue and the ability to use that cue to direct its interaction with its environment, *O* is equipped to cope with the complexity of its surrounds; a simple tactile perceptual system, in becoming an anticipatory system, allows *O* to avoid dangerous situations prior to encountering them.

The take home message from this thought experiment is that behaviour that is driven by anticipatory processes *poises* organisms to respond to possible deleterious environmental perturbances and/or to avoid prolonged physiologically stressful and/or homeostatically destabilizing states prior to their actually occurring. If, as ECT postulates, cognition evolved as a way of dealing with environmental complexity, then, baring the assumption that cognition has been exapted for some other function, situations in which there are cognition-using living systems that fail altogether to face malign environments may not happen very often or play out for very long when they do. From the perspective of ECT, the behaviour of an organism that engages purely in responsive activities (e.g., metabolic processes) would fail to qualify as an expression of cognition because responsive activities are not sufficient for coping with environmental complexity; anticipation as opposed to mere reaction seems to be something that is crucial for dealing with the kind of environmental complexity that presents direct challenges to an agent's continued self-preservation.

The notion that anticipation is fundamental to cognitive systems may be traced at least as far back as the research programme of cybernetics (Wiener, 1948; Ashby, 1952; Conant & Ashby, 1970). According to this programme, the role of anticipation is central to homeostatic maintenance in goal-directed adaptive systems. A system may maintain its stability, returning its controlled variables (i.e., physiological variables in the case of living-systems) to their viable range when disturbed, by using a combination of feedback and feedforward closed loop mechanisms to govern its interaction with the environment. Importantly, rather than waiting to register a discrepancy between the values of the controlled variables that it should occupy and those values that it does currently occupy (e.g., waiting to feel the effects of oxygen depletion in a closed room), a living system that is equipped with a *forward model* (i.e., a model that captures the anticipated effects of its regulating actions upon its environment) can avoid deleterious disturbances to its organization prior to their occurring (e.g., opening the room's window prior to hypoxia occurring).[13] Another manner of understanding anticipation that falls out of cybernetics looks not at the possession of models by a homeostatic system but

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[13] This process that I've described is generally referred to as allostasis. More specifically, allostasis is defined as achieving stability through change in both physiological and behavioural systemic parameters (Sterling, 2004).

rather at the self-regulating system itself as a model of its environment (and the effects of itself acting upon its environment). The "good regulator theorem" (Conant & Ashby, 1970) states that "every good regulator of a system must be a model of that system" (p.89). Accordingly, in this sense living systems are models of the environments that they regulate and as such they come to anticipatorily capture the effects of their actions upon their environment.

What of the relation between anticipation and living systems? The notion that life is an anticipatory process is one that has been supported in great detail by the work of theoretical biologist Robert Rosen (2012), who in his seminal book *Anticipatory Systems* models biosynthetic pathways (and living systems more generally) as anticipatory systems. He defines an anticipatory system as one that "contain[s] a predictive model of itself and/or its environment, which allows it to change state at an instant in accord with the model's predictions pertaining to a later instant" (2012, p. 313). Living systems accordingly may be cast as anticipatory systems that use self-generated predictive models to modify themselves, pre-empting their own destabilization.[14]

It should be noted that in both of these accounts of anticipation in cognitive systems and in living systems there is an explicit emphasis upon the use of models. This being said, there are other accounts of anticipation (and anticipatory systems) that avoid the use of models in their proposed explanations (see Riegler, 2001; Stepp & Turvey, 2010; Bickhard, 2016). Rather, such model-free accounts see anticipation as "aris[ing] from the system itself via lawful regularities embedded in the system's ordinary mode of functioning" (Stepp & Turvey, 2010, p. 2). Accordingly, the internal dynamics of the organism are biases which anticipatorily 'nudge' organisational processes to certain attractor states rather than others in response to the dynamics of the environment that it is coupled to.

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[14] See Nasuto & Hayashi (2016) for an interesting account of how this notion of anticipation can be used to inform cognitive robotic technologies.

In attempting to shed light upon strong life-mind continuity, this thesis will deploy two model-based anticipatory frameworks (the Free Energy Framework and predictive processing) along with a model-free anticipatory framework (ecological psychology). It will be assumed throughout that the active adaptation that underwrites life and mind is an anticipatory process. Let us now turn to an overview of each of the three frameworks that will be deployed over the course of this thesis.

0.4 Anticipatory cognitive frameworks

In this thesis I have chosen three different anticipatory cognitive frameworks to investigate strong life-mind continuity and the various forms of cognition that strong life-mind continuity can help to make sense of.[15] The three anticipatory frameworks that will be deployed—sometimes concurrently and sometimes separately—are the Free Energy Framework, predictive processing and ecological psychology. I choose these frameworks for three reasons: firstly, given what has been suggested above about the relation between adaptation and anticipation, these anticipatory frameworks are ideally placed to investigate the possible relation between active adaptation in cognitive systems and in living systems and hence to investigate strong life-mind continuity. Secondly, because each of these frameworks emphasize the interaction between embedded cognizers and their embedding environments as essential to cognitive explanation, I find that they are able to do justice to the fact that cognition does not happen in a vacuum (Wilson,1994; Hutchins, 1995; Clark, 1997; Rowlands, 1999). Lastly, each of these frameworks take interestingly different starting points in providing an account of cognition. As

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[15] A theoretical framework may be roughly understood as an analytical structure that constrains and guides theoretical investigation of a given phenomenon (or phenomena). This structure may include concepts, assumptions, and theoretical commitments.

will become apparent below and in later chapters, while the Free Energy Framework starts from considerations about the self-preservation of living systems and predictive processing starts from considerations about cognitive architecture, ecological psychology begins from *methodological* considerations concerning the ongoing cause and effect relationships of the organism on its environment and the environment on the organism.[16] Given that these starting points lend themselves to distinct and yet sometimes overlapping theoretical perspectives on cognition, the various commitments, assumptions and theoretical apparatus that accompany each perspective can be contrasted, compared, and synthesized into a larger encompassing framework which this thesis will use to guide the investigation of strong life-mind continuity.

One of the recurring themes of this thesis is that the conceptual apparatus of one framework might be used to inform and/or constrain the others and help build a more complete picture of cognition and a more holistic account of life and mind. These differences will be used instrumentally to mark out different forms of cognition and possible explanatory limitations of the particular frameworks under consideration. In other words, where one framework fails, another may succeed in offering its apparatus to account for and constrain putative cognitive phenomena. Thus, an overarching aim of the thesis is to identify instances where the explanations and apparatus provided by one framework may be said to enrich the other which is suited to explain cognitive processes and phenomena up to a certain level of complexity. For example, while the Free Energy Framework and ecological psychology may help expose and account for forms of cognition in unexpected places (e.g., bacteria and plants), given its emphasis upon precision weighted prediction driven dynamics (something which will be discussed in detail in chapter 4), full-blown predictive processing might be considered to demarcate a transition

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[16] While the ongoing open exchange between the environment and agent is also a central feature the way cognition and life are modelled in Free-energy Framework, this exchange for ecological psychology is both central to its analysis of perception and action, and importantly describes its methodological approach to the question “what is perception?”

from minimal cognition to the very kind of decoupled cognitive capacities that are definitive of human cognition. By deploying these anticipatory frameworks, this thesis aims to distil what makes the self-preserving processes of life continuous with that of the more general adaptive process of cognition, and to locate possible "transition markers" (Ginsburg & Jablonka, 2019) in cognition along the way to the kind of enriched processes which are distinctively human. Transition markers are "criteria that may be used to mark different forms of life that can persist over time" (Ginsburg & Jablonka, 2019, p. 27).[17] Such transition markers help us to understand how strong life-mind continuity is consistent with the complexification of lifeforms; they provide the possible loci at which life has become further enriched and at which cognition has become further diversified. Let us now look at each of these frameworks.

0.5 The Free Energy Framework

The Free Energy Framework (FEF) (Friston, 2005; Friston & Stephan, 2007; Friston, 2010) is a powerful and ambitious unifying cognitive framework that has been deployed to account for a vast array of phenomena in both theoretical biology and biophysiological neuroscience, ranging from the adaptive behaviour of bacteria (Auletta, 2013; Corcoran, Pezzulo & Hohwy, 2019), morphogenesis (Friston, Levin, Sengupta, Pezzulo, 2015) and natural selection (Campbell, 2016) to neuropsychological disorders in humans (Parr & Friston, 2018). FEF begins with the fundamental assumption that any living system, in maintaining its structural and functional integrity will appear to (temporarily) violate the second law of

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[17] It should be noted that a transition marker is not necessary or sufficient condition for the expression of some mode of being but is rather a diagnostic characteristic that allows scientists to reverse engineer the mode of being under investigation (Ginsburg & Jablonka, 2019).

thermodynamics, avoiding (near) global thermodynamic equilibrium while maintaining (near) local thermodynamic equilibrium. A living system is thus one which will tend to revisit a limited range of states (defined over a state space of all possible states it could occupy) over time despite the influence of random environmental fluctuations. The fact that a system exists at all entails that it continues to remain distinct from its milieu.

Another assumption that falls out of the fact that a living system must remain distinct from its environment is that such systems must possess a boundary separating it (i.e., the states that define it) from its environment. This boundary is mathematically describable with the Markov blanket formalism (Friston, 2013), a statistical construct borrowed from Bayesian graph theory (Pearl, 1988). In short, a Markov blanket describes the set of boundary states (i.e., active states, and sensory states) that induce a statistical conditional independence between a system's internal states and its environment (i.e., external states)[18]. The conditional independence induced by a Markov blanket means that internal states and external states can only influence one another by way of blanket states. A bacterium is a somewhat intuitive example of how this partition may be applied to a living system. A bacterium's cell membrane states may be cast as its sensory states; its flagellar activity and/or states of its actin filaments correspond to its active states; the activity of its intracellular states corresponds to its internal states; the conditions of the bacterium's surrounding milieu beyond its Markov blanket correspond the external states. As long as the bacterium's internal states continued to be enshrouded by a Markov blanket, its internal states may resist change despite change in the surrounding environment. By deploying the Markov blanket formalism, FEF uses a mathematical tool to ontologically individuate living systems from the environments which their behaviour adapts them to.

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[18] The Markov blanket formalism will be fleshed out in detail in chapter 3.

A further assumption, and one that is crucial to understanding FEF's status as an anticipatory framework, is that any biological organism embodies a *generative model* of its niche and its behaviour in its niche. When approached from the perspective of Bayesian statistics, a generative model is understood as a network of 'beliefs' (i.e., a joint probability density) that a living system's morphology, phenotype and the tendencies of its internal states are an expression of.[19] Because they parameterize a probabilistic mapping between sensory states and the environmental states which cause those sensory states (Corcoran, Pezzulo & Hohwy, 2019), generative models are used to estimate—via processes that approximate Bayesian inference—the environmental causes of sensory states.[20]

Generative models may be equally approached from the perspective of the physics of flow. From this perspective models may be described in terms of an attracting set of states that a self-organizing system tends to frequent over the course of its existence - living systems being one kind of self-organizing system. That is, from all possible states in a phase space that a living system could possibly occupy, it will tend to return to a limited neighbourhood of states when perturbed (Friston, 2019b). This attracting set of states that underwrites a living system's dynamics is referred to as its *non-equilibrium steady state density* (NESS); it is equivalent to that system's generative model (Friston, 2019b; Ramstead et al., 2019; Palacios et al., 2020). A living system is one that (self) organizes around energy gradients, behaving at different interacting timescales (i.e., from cellular responses to overt sensory-motor behaviour) in ways that—when everything goes well—ensures that

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[19] Care should be taken to avoid conflating these statistical 'beliefs' from the personal level beliefs of folk psychology.

[20] Approximate Bayesian inference conforms to Bayes' Rule:

$$P(H|E) = \frac{P(E|H)\,P(H)}{P(E)}$$

Where H is the hypothesis and E is evidence, Bayes rule states that the probability of the hypothesis conditioned on the evidence, $P(H|E)$ (i.e., the posterior probability) is proportional to the product of the probability the evidence conditioned on the hypothesis (i.e., the likelihood) and the probability of the hypothesis (i.e. the prior) over the probability of the evidence (i.e., the marginal likelihood or what is also referred to as model evidence).

its dynamics flow towards its NESS (see chapter 3). For a living system, failure to do so means failing to remain distinct from its environment and hence eventual dissipation, death, and decay.

An organism's behaving in ways that garners evidence for its generative model is equally the manner in which its Markov blanket is preserved and the manner of flowing towards its NESS density. In other words, a system's behaving in ways that garners evidence for its model is tantamount to its garnering evidence for its own existence. That this is the case, follows from the assumption that any organism that continues to exist embodies a model of its environment.[21] In this sense, according to FEF, an organism does not *possess* a generative model of the causal structure of its environment, but it *is* a model of that causal structure (Friston, 2013) (see also Bruineberg et al., 2016). This approach to generative models may thus be seen as a recapitulation of *the good regulator theorem* (Conant & Ashby, 1970). In the case of the cognizing organism, such a self-organising system must regulate the dynamic, yet regularly structured, environmental energies which it comes into contact with on a continuous basis. Thus, the embodied cognizer in learning the causal regularities of its world becomes a model of its world and of the effects of its acting upon its world. Here, then, 'model' is to be understood "in the most inclusive sense, as combining interoceptive dispositions, morphology, and neural architecture, and as implying a highly tuned 'fit' between the active, embodied organism and the embedding environment" (Friston, Adams, Perrinet, & Breakspear, 2012, p.6). Importantly, this suggests that generative models are not merely in the business of biophysically encoding accurate (statistical) descriptions of sensory and environmental states, but they are first and foremost in the business of guiding long-term, self-preserving action. Crucially, FEF does not presuppose that any particular kind of anatomical structure must be in place for the existence of a generative model. This has the consequence that both neural organisms and

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[21] The notion of generative model employed here is in many ways analogous to the notion of anticipatory models proposed by Rosen (2012).

non-neural living systems (e.g., bacteria, plants, etc.) alike entail the existence of generative models over the duration of their continued existence.

According to FEF, one way an organism may preserve its structural and functional integrity despite the global tendency for entropic increase is by both evaluating and reducing *surprise* (also referred to as “surprisal”). Surprise is an information-theoretic measure of disorder, quantifying how improbable sensory state observations are for a given kind of organism. Sensory states in the context of FEF are those states that are those states of an organism’s sensory receptors. Any persisting organism will have a higher likelihood of occupying certain sensory states and not others. This set of likely sensory states is associated with that organism’s viability. An organism’s occupying sensory states outside this viable set is improbable and the further removed from this set sensory states are, the higher the quantity of surprise is. Surprise may thus be cast as system-relative error. For instance, in contrast to a human, a fish’s being out of water will result in high quantities of surprise given the kind of biological water-inhabiting system it is.[22] However, given that evaluating surprise requires that a living system has access to all of the near infinite possible sensory states which it could occupy (which, needless to say, it does not), evaluating surprise is computationally intractable. The free-energy principle states that any organism that exists, continuing to avoid global thermodynamic equilibrium, will optimize its internal states (i.e., predictions) and action states (i.e. behaviour) so as to minimize *free energy*. Free-energy is a measure of the difference between the sensory states an organism expects to observe given its generative model and those that it actually observes at its sensorium. Because free-energy is an upper bound on surprise (i.e., free-energy always greater than or equal to surprise) and is something that an organism has access to it can be used to approximate surprise (Friston, 2009,

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[22] Information theoretic surprise should not be conflated with the personal-level feeling of surprise.

2010). Moreover, FEF suggests an elegant mathematical manner in which free-energy is minimized: *active inference*.

Active inference is a solution to an optimization problem. By optimizing its internal states over time an organism may reduce discrepancies which arise between its internal states and the sensory states. Because, as we have just seen, this discrepancy may be quantified as free energy, reducing the discrepancy is the same as reducing free energy. This process of minimizing free-energy via internal-state optimization is referred to as perception. Free-energy is also minimized by action state optimization, what is referred to as action. This occurs when internal states drive action state change in ways that modulate the organism’s relationship to its environment, bringing about the kinds of sensory states that it expects. Although optimizing internal states minimizes the upper bound on surprise, it is only this process of action state optimization that can reduce surprise, thus returning the living system to the set of viable states which its existence depends upon.[23] Because optimization is driven by the dynamics of the generative model, Free-energy minimization is evidence for the generative model which governed the changes in internal states and active states. Thus, it follows that by engaging in this process of active inference, (when all goes right) an organism minimizes free energy, minimizes surprise and thereby maximizes evidence for its generative model. Importantly, if a living system is a model of its environment, then by minimizing free-energy via perception and action (i.e., active inference), an

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[23] That this is the case can intuitively be captured by imagining the different outcomes arising from either updating your belief so as to accurately represent that there is a polar bear (rather than a person in a polar bear suit) quickly approaching you or fleeing to avoid contact with the approaching bear. Arriving at an accurate belief is useful in this situation, but alone it might result in the highly unexpected (high surprise) sensory observations that accompany your being a polar bear’s next meal. It is only by using that belief to direct action in an appropriate manner (i.e., fleeing) that you are likely to avoid harm’s way. This example illustrates the more general idea that free-energy minimizing living systems are embedded in dynamic environments replete with selection pressures. The nature of these pressures often demand that living systems not only change themselves (i.e., change their expectations), but also initiate behaviour that changes their relationship to their environment (i.e., action).

organism maximizes the evidence for own existence (i.e., it remains well-adapted to its environment).

Importantly, perception and action in FEF need not map neatly on to our folk psychological understanding of those concepts. In this manner FEF challenges our folk psychological conceptions of perception and action, conceptions that are heavily informed by paradigmatic human capacities (and by our folk-biological conceptions as it will be illustrated in chapter 3). FEF thus allows for a broader approach to understanding how a range of living systems, in virtue of their sensitivity and adaptive response to the complexity of their milieus, possibly exercise a range cognitive capacities.[24] It is in virtue of active inference, the central workhorse of FEF, that cognition and life are elegantly brought together; by acting on the environment in ways that reduce the (real-time and expected) discrepancy between the sensory states that they (expect to) observe and those that they ‘prefer’ to observe, living systems actively preserve themselves and garner evidence for the generative models that their organization and patterns of behaviour instantiate. Importantly, if FEF is correct, both anticipation (i.e., prediction) of the sensory states that would be observed were certain actions performed and anticipation of sensory states that should be observed relative to a given phenotype play a fundamental role in the processes of life and mind.

Let us now turn to another anticipatory cognitive framework which will be used in the following chapters to illuminate LMC.

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[24] Corcoran et al. (2019) have insightfully interpreted the notion of dealing with environmental complexity as described by Peter Godfrey-Smith (1996) as free-energy minimization (or equally the reduction of uncertainty).

0.6 Predictive processing

As it has developed over the course of the last 10 years, the predictive processing framework (henceforth PP) has taken many forms, ranging from ‘brain-centric’ views (e.g., Hohwy, 2013) to various grades of embodied and enactive views (Clark, 2016; Orlandi, 2016). The former kind of view emphasizes the brain and brain processing as central to (and perhaps sufficient for) satisfactory explanations of cognitive phenomena. The latter view, in its more moderate form, sees brains and brain processing as central to cognitive explanation but also emphasizes the important (and often necessary) roles that bodies and bodily interaction with the environment play for satisfactory cognitive explanation. In this thesis I shall be primarily concerned with one form of predictive processing, action-oriented predictive processing, developed by Andy Clark (2013,2016a), a form that is located closer to the embodied and enactive pole of PP. The following outline of the characteristics of this framework, however, will for the most part be applicable to all forms of PP unless otherwise noted. More generally PP is a cognitive framework which, although often located within the broader FEF, may be used independently of FEF. Although there are many features which PP and FEF share (e.g., generative models, active inference, error and (approximate Bayes-driven) hierarchical error minimization), there are some important differences. By making these similarities and differences explicit, we may glean a better general picture of PP (and FEF) and how it too qualifies as an anticipatory cognitive framework.

Whereas FEF arrives at an account of anticipatory cognition by beginning with a fundamental principle about what it is to remain alive, PP begins with a general Helmholtzian assumption about the nature of cognitive processing and offers a testable process theory of cognition from this assumption. According to this Helmholtzian assumption the brain is an environmentally isolated, hypothesis-generating organ and the only access it has to the world is through the mediating flows of sensory input which it is sensitive to. Perception is seen as the ongoing result of the brain's active generation and testing of explanations (hypotheses) for the evolution of sensory signals across the sensorium.[25] Given the causal relation between the structure of the environment impinging upon the sensorium and the sensory signals, the brain (subpersonally) infers the structure of the environment from the impoverished sensory signals. These sensory signals are ambiguous in that the same signals can be caused by many different structures in the world and different signals can be caused by the same structure. Moreover, because these ambiguous sensory signals exhaust the information that the brain has about the world, this results in an "inverse problem" (Marr, 1983) of how it is possible to accurately identify (perceive) the cause from such an impoverished sensory array.[26] PP, by making use of the Helmholtzian assumption, solves this inverse problem; perception is seen not as process of filtering and classifying but as one of the brain's unconsciously inferring the causes of the sensory signals it has access to.[27] PP suggests that the brain *actively* arrives at its best (i.e., most probable) guess about the distal causes of the sensory signals that it has access to by engaging in a process of reiterative and hierarchical prediction error minimization. Here, error quantifies the discrepancy arising from the comparison of brain-generated predictions and the incoming sensory signals that predictions target. To minimize prediction error is thus to minimize this discrepancy. It is when the brain settles upon its best guess about the amalgam of hidden causes across many spatio-temporal scales that it "has self-generated the sensory data using stored knowledge and perceives a meaningful, structured scene'' (Clark, 2016a, p. 21) Essential to this kind of account is the idea the brain is not a passive

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[25] See Gregory (1980) for a similar account of perception as hypothesis testing.

[26] von Helmholz (1867/1910), motivated by the notion that the brain does not have direct access to the causes of its sensory signals, suggested that perception was a process of unconscious inference.

[27] It should be noted however that some PP theorists have suggested to bypass both the perceptual inverse problem and the unconscious inferential manner of dissolving it altogether by placing emphasis upon an idea borrowed from J.J. Gibson's (1966,1979) ecological psychology that there is rich information for disambiguation available in the environment (see Anderson, 2017; Orlandi, 2016). We shall return to this notion of environmental information below in section 0.5.

information processor, but that it is engaged in the endogenous generation of predictions which meet incoming sensory signals (Clark, 2016a).

Thus, perception is understood to come about in virtue of hierarchical bidirectional message passing involving the comparison of sensory signals originating from the body and world with signals originating from the brain and the reiterative reduction of residual error between the two. Importantly, PP holds that this process is able to account for most (if not all) cognitive phenomena. Action, perception, learning, and planning are “seen as profoundly unified and, in important respects, continuous” (Clark, 2013, p.7), all being driven by the hierarchical process of minimizing discrepancy between world-generated and brain-generated signals across different timescales; perception arising from error minimization at faster scales, and learning being the result of error reduction at slower timescale. Crucially, all of these processes may be accounted for in PP, without being committed to the kinds of assumptions that are central to FEF. For example, PP need not be committed to a statistical view of life. Thus, it may provide an account of cognition in terms of hierarchical bidirectional message passing and error correction without invoking the free-energy principle or its corollaries. As such, from the perspective of PP, there may be living systems (and cognitive systems for that matter) that minimize free-energy but do so in a manner that fails to qualify as PP. Such systems fail the capacity to engage in *environmentally decoupled cognitive processing*, the kind of processing that underwrites complex cognitive capacities like planning, mental imagery, and thought.[28] This being said, action-oriented PP, places emphasis upon satisficing action rather than constructing accurate generative models of the environment and as such, it emphasizes the adaptation of the organism to a complex environment as the ultimate driving force in cognition. Because action-oriented PP acknowledges a relationship between cognition and adaptation in *some* living systems (i.e., it sees cognition as playing

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[28] This is not to say that PP agents do not also engage in environmentally coupled processes. Rather, the point is that agents deploying PP architectures are not limited to the use of environmentally coupled action-perception loops.

the fundamental role of supporting adaptive behaviour), is a valuable resource with which to investigate strong life-mind continuity.[29] Having made the difference in starting points between PP and FEF explicit, let us now look at the various characteristics of PP in detail.

Like FEF, the construct of a generative model is central to PP. Importantly, whereas both statistical 'beliefs' and NESS densities are equally valid manners of describing generative models in FEF, the NESS interpretation is something that is theoretically extrinsic to PP. For PP is generally committed to the Bayesian interpretation of models and belief update.

Another important difference between the manner in which PP and FEF envision generative models is that according to PP, in order for the kind of complex hierarchical prediction dynamics distinctive of PP to arise, generative models require the kind of physical hierarchical organization exhibited primarily by the anatomical structure of the brain (or something brain-like). According to PP, generative models are the brain's best guess at the 'hidden' causes of sensory signals that it has direct access to; they are understood as the rich and integrated global patterns of network connectivity distributed across and between the information processing hierarchies of the brain. Each cortical layer of the generative hierarchy endogenously issues cascading (top-down) statistical estimates (i.e., predictions) of the forward flowing (bottom-up) sensory and/or error signals in the cortical layer below it. Over time, in virtue of successfully being able to reduce the discrepancy between the top-down and bottom up signals (i.e., prediction error) at many layers, the dynamic activity of the generative model comes to capture the nested hidden causal structure of the environment that gave rise to such sensory flows. Brains, due to their hierarchical structure allow for

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[29] PP does not have to be applicable to all living systems in order for it to be a valuable framework for understanding strong life-mind continuity; its value is located in its ability to help think about specific forms of enrichment.

temporally deep prediction dynamics.[30] Models with a high degree of temporal depth capture statistical regularity over long timescales and can be used to predict the outcome of actions that have not—or may never be—performed. Hence models with a high degree of depth are thought to underwrite the ability to engage in decoupled cognitive processing (see Pezzulo et al., 2015).

In contrast, although generative models are often assumed to be hierarchical, FEF does not gravitate towards any particular anatomical manner in which they must be implemented; every living system that exists—from plants (Calvo & Friston, 2017) and bacteria (Auletta, 2013) to humans—embodies a generative model of the structure of the environment it must anticipate in order to adaptively behave. FEF, but not necessarily PP, sees the kind of structure the brain has (i.e., hierarchically organized cortical layers) along with the body's gross morphology and physiology as expressive of the fact that generative models are learnt at phylogenetic timescales in addition to being learnt at ontogenetic timescales. For example, according to FEF, the fact that the structure of the brain is organized hierarchically, recapitulates the nested and hierarchical structure of the environment which the brain and its activity has become a model of (Friston, 2019a). Moreover, FEF acknowledges that all living self-organizing systems entail generative models with some degree of temporal depth. Unlike PP, which is thought to require a high degree of model depth for the kind of prediction error dynamics that it describes to take place (Clark, 2017), in FEF there is no particular degree of depth at which free-energy minimization begins to arise.[31]

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[30] Seth (2014) refers to models that possess temporal depth as "counterfactually rich models" because they roughly capture the counterfactual conditional structure 'were action A to be completed, sensory outcome O would be observed.

[31] That PP places a demand on temporally deep models is made evident when Clark (2017) in a footnote writes: "Among those systems, those equipped with generative models that enable them actively and systematically to anticipate how the world will alter in response to their own possible future actions plausibly constitute the sub-class most demanding of the full predictive processing interpretation" (p. 5).

There is one further construct of PP which requires brief explication that is indispensable to the PP cognitive framework and one that is backgrounded in many FEF explanations: *precision weighting*. Not only are the forward propagating signals being met and recurrently estimated at many different cortical levels by descending predictions, but those very same bottom-up signals as they are propagated forward are being estimated and modulated so as to reflect their reliability. This process, precision weighting of error, may be understood statistically as tracking the inverse variance of a probability distribution over the error. The higher the precision a sensory/error signal is assigned, the more informative (i.e., reliable and/or valuable relative to the current pragmatic context) that signal is estimated to be.[32] The weighting itself is thought to occur biochemically in virtue of increasing postsynaptic gain within superficial pyramidal cells (Bastos, et al., 2012) via the regulation of neuro-modulators such as—but not limited to–dopamine (Friston, 2012; Lawson et al., 2014) and acetylcholine (Friston, 2008).[33]

Precision weighting estimation thus determines the relative influence of the bidirectional signals; by increasing the precision weighting of a sensory/error signal, that signal comes to play a greater role in determining which streams of prediction error ascend to higher levels of the hierarchical generative model. With respect to top-down signals, precision weighting plays an important role in

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[32] One neat example that Clark (2016a) uses to illustrate the effects of precision weighting is the move from the indecipherability to the stubborn decipherability of sinusoidal speech recordings. These are speech pattern recordings that have been treated by applying ring-modulation effects. Prior to decoding sinusoidal speech is indecipherable, sounding merely like a metallic pattern of tones. However, when a subject hears the original speech recording without the ring-mod effect, and then listens again to the sinusoidal speech of the same recording, the pattern of words that was once indecipherable remains salient. This odd phenomenon is explained by PP in terms of precision weighting; after hearing the unaffected speech recording, certain sensory signals associated with particular words (or syllables) are precision weighted, influencing which streams of error drive 'belief' update. When listening again to the sinusoidal version of the speech pattern, the spoken sentence stands out of the sinusoidal cacophony given that the precision weighted sensory signals remain salient drivers of the top-down prediction dynamics.

[33] The weighting itself has been hypothesized to occur biochemically in virtue of increasing postsynaptic gain within superficial pyramidal cells (Bastos, et al., 2012) via the regulation of neuro-modulators such as—but not limited to–dopamine (Friston, 2012; Lawson et al., 2014) and acetylcholine (Friston, 2008).

selectively driving the kinds of predictions generated by narrowing the scope of information that elicits those predictions. As such, it has been suggested that attention itself is a “means by which certain error unit responses are given increased weight, hence becoming more apt to drive response, learning. […] and action” (Clark, 2016a, p.57). Furthermore, if bottom-up signals are estimated to be unreliable, the most statistically probable predictions issued by the generative model exert more influence over what is experienced until better environmental conditions arise (or are sought out) that provide reliable sensory signals. Precision weighting, thus, allows for and simultaneously constrains what might be thought of as a contextually sensitive balancing between the impact of bottom-up sensory signals and top-down predictions. Whichever of the two signals (bottom-up or top-down) is thought to be the most reliable and informative—relative to one’s current aims—plays a larger role in driving experience and action (Hohwy, 2013; Clark 2013,2016a; Seth, 2014).

Crucially, although the brain plays an essential role in implementing the predictive hierarchy, PP—at least in its action-oriented form—need not discount the role of the active body (Clark, 2015,2016a, Friston, 2012). At the heart of PP is the claim that cognition emerges as the result of the anticipatory operation of hierarchical, bidirectional, precision weighted prediction error minimization. One effect of successful prediction error minimization is providing maximum evidence for the statistical generative model which thereby reflects the organism-relevant regular structures of its environment. In addition, such error reduction may be seen as signalling sensory information that has effectively been made available for possible action (Clark, 2016a). Action-oriented PP’s emphasis on the role of active inference (as contrasted to perceptual inference) as a means to minimize error brings along with it an important emphasis upon the role of the entire body and body-environment interaction. It is the active dynamics of the brain-body-world system that brings about prediction error minimization even if the primary locus of the PP cognitive architecture centres around neural processing in the brain.

With this overview of PP in hand, let us now turn to the third anticipatory cognitive framework that this thesis will use in its investigation of strong life-mind continuity.

0.7 Ecological psychology

The framework of ecological psychology EP, spearheaded by James J. Gibson (1966,1979) and further developed by psychologists Michael Turvey, Robert Shaw, E.S. Reed, & William Mace (1981), Clare Michaels & Claudia Carello (1981) and William Warren (1984,2005) takes its starting point as an anticipatory theory of perception and action from the notion of *organism-environment mutuality*: the perceiving and behaving organism and its perceptible and behaviour-relevant environment mutually imply one another such that neither perception nor action may be successfully accounted for without taking the organism's relation to its econiche into consideration (Gibson, 1966,1979; Turvey et al., 1981; Warren 2005). More generally, the organism cannot not exist without an environment and vice versa. To explicate the environment's place in a perceptual theory is thus crucial "since what there is to be perceived has to be stipulated before one can even talk about perceiving it" (Gibson, 1979, p.2).This mutual implication may be understood in terms of a *niche* or evolving organism-environment system wherein the possible behaviour of the organism complements the kind of environment it inhabits and the kind of environment it inhabits complements the kind of behaviour which the organism may possibly engage in.

Another significant feature of EP is that it aims to provide a common analysis of what perception involves in a wide range of organisms which engage in adaptive behaviour.[34] An account of perception should be able to not only say something about the way humans perceive in their niche but also be, at core, applicable to the way spiders, birds, and other non-human animals might be said to perceive in each of their respective niches (Barrett 2011). Although this is the case, EP stresses that attention must be given to the fact that there are different species-specific perceptual systems, which by prolonged organisms-environment interaction over evolutionary timescales have become sensitive to different structures specific to an animal's econiche.

This brings us to the central feature of EP, its notion of *environmental information*. Gibson's theory of environmental information begins with the observation that objects, or more specifically, substances, structured surfaces, textures, and relations amongst them, are what populate the environment. Light, the medium of vision, when radiating from some source, reflecting off surfaces and then onto a point of observation, captures the structure of those objects and the relations amongst them. This structured light, what Gibson termed the *ambient optic array*, specifies in a one-to-one manner the surface layout and texture of its causes in the environment in relation to the perceiving organism. Crucially, it is by a perceiver's moving around the environment or the environment moving in relation to the perceiver that information about the structure of the objects and their relations are 'picked-up' by the perceptual system.[35] Gibson argued that such movement, from the point of observation, generates mathematically describable light transformations amongst the relative angles of the array with respect to the point of observation, revealing an underlying *invariant structure* across behaviourally

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[34] That Gibson's analysis of perception is meant to be generalizable to all visually perceiving animals is evident when he argues that retinal images are not necessary for vision. He does so by invoking the fact that arthropods see despite their having compound eyes (see Gibson 1979, p. 62). This implies that an ecological account of vision should aim not only at an analysis of perception for vertebrates and molluscs with chambered eyes but for animals with distinct visual systems. More generally, the ecological account of perception in all modalities is not constrained by anatomical features *per se* and thus may be deployed in accounting for a wide array of cases in which organisms with strikingly different anatomies adaptively respond to organisms-specific opportunities for action in their niches.

[35] More will be said about the notion of *information pick-up* in chapter 2.

induced transformation. ‘Structural invariants’ lawfully specify—in a one-to-one manner—the properties of objects located in the environment and are behaviour relevant and rich sources of information about them. Texture gradients and optic flow are commonly understood as being examples of such invariants.[36] Moreover, given the active nature of invariant harvesting, that which is made available in virtue of a perceiver’s movement not only corresponds to properties of objects in the environment but also to various properties of the perceiver (i.e., relative location, direction of motion, acceleration or deceleration, etc.) In this way, environmental information specifies something about both the environment and the perceiving organism in relation to its environment.

Environmental information for perception and behavioural guidance is held to be both *abundant* and *rich*. To say that information is abundant is to say that it is readily available in the environment for all perceptual modalities. In other words, “information in ambient light, along with sound, odour, touches, and natural chemicals, is inexhaustible” (Gibson, 1979, p. 243). To say that information is rich means that it sufficiently specifies the surface layout and textures in the environment in a one-to-one manner. The importance of this cannot be understated with respect to comparing EP to PP. For the inverse problem that unconscious inference solves fails to arise under the assumption that there is rich environmental information that does not need to be disambiguated in the first place. Thus, the availability of rich environmental information suggests that there is no need for the construction of internal models, inference or use of memory to infer and disambiguate the causes of sensory stimulation. Perception-action, according to EP, does not begin with ambiguous stimulation that stands in need of enrichment by top-down knowledge or priors. Instead stimulation is already richly

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[36] Texture gradients, gradual changes in the size of textured elements of a surface, relay information about both depth and distance. The smaller the texture the further away from the point of observation the surface is. Gibson also introduced the notion of optic flow, which is the spatio-temporal pattern of outward flowing blur produced by moving in a single direction. The centre of this flow pattern is non-blurred when one’s direction remains fixed and thus, by its being invariant over movement (i.e., transformation) it is able to deliver relative information about steady forward motion maintenance.

structured (cf. Orlandi, 2016). Environmental information is something which is altogether absent from PP (see Anderson & Chemero, 2019). This being said, EP like PP and FEF stresses that perception and action are mutually guiding activities. Unlike PP and FEF, which describe this coupled process in terms of active inference, in EP action and perception together allow for disambiguation; by actively picking-up on invariant structure in the array an agent is able to disambiguate between what might otherwise be (i.e., when not moving) ambiguous information. Part of the richness of environmental information is that it is available for active discovery; the ability to explore the environment further being "an absolutely essential aspect of the adaptive behaviour of organisms and therefore, of the ecological approach to perceiving and acting" (Turvey et al., 1981).

This brings us to another central feature of EP: *direct perception*. EP holds that because perceptual systems can detect environment-specifying information without the use of mediating internal models, inferential operations upon sensory input, memory or internal representations more generally, the process of perception is *direct*. Perception exclusively involves the detection of and coupling to available environmental information by the perceptual system (i.e., the sensory organs and the moving body). Given that environmental information is not seen as impoverished, there is no need for processing involving the use of memory states to supplement such information.

Although direct perception stresses online, moment to moment sensorimotor coupling to the environment, just what this coupling allows an organism to perceive is not limited to the present. To get a feel for how EP is an anticipatory theory of perception-action, let us look at what is arguably one of Gibson's largest contributions to cognitive science and perceptual studies, viz. his theory of affordances. In addition to perceiving objects and events, Gibson held that organisms perceive what he called *affordances*. Affordances are organism-specific opportunities for behaviour that the environment offers (Gibson, 1979). They are organism-specific in that they exist relative to the existence of certain morphological features, physiological states and skills possessed by agent-perceivers. As such, affordances are an eloquent manner of fleshing out the Gestalt notion that objects have a “demand character” (Koffka, 1935) which imbues them with perceivable pragmatic value. For instance, although a non-vertical, pliable branch high up in a tree might afford ‘perch-on-ability’ for a kestrel given its bodily features and ability to land, for a human the same branch affords no such thing. The kestrel prior to landing perceives the branch as something that has value in relation to its behavioural repertoire and its current situation (e.g., requiring a position high in a tree to perch and track its prey below). In perceiving affordances, an organism directly perceives something about the structure of the environment and simultaneously something about itself. It follows that affordances are understood to be higher order invariants (i.e., invariant structure in the environment as a function of the invariants that describe the states of the living system) (Gibson, 1979). Importantly, because affordances are *possibilities* for action, affordance perception, although direct, is anticipatory. In perceiving an affordance, rather than perceiving what is being exploited, an organism perceives that which *could be exploited* were it to bring intermediate actions about that are conducive to such exploitation. As such affordance perception may be seen as intrinsically future-oriented (see Turvey, 1992; Bruineberg, et. al. 2018).

Having outlined the characteristics of FEF, PP and EP, the manner in which each may be considered an anticipatory cognitive framework is represented in Table 1.

	Anticipatory Features of Cognition
Free Energy Framework	Action is guided by (and guides) model generated internal states that allow an organism to avoid and/or adaptively respond to anticipated deviations from the limited range of sensory states that it tends to occupy given the kind of organism it is.
Predictive processing	Action is guided by (and guides) model generated, precision weighted predictions that allow an organism to minimize the anticipated discrepancy between its best predictions of the incoming sensory signals and the sensory signals that it actually encounters.
Ecological psychology	Action is guided by (and guides) the direct perception of species-specific, future-oriented opportunities for action that the environment offers (i.e., affordances).

Table 1: Anticipatory features of cognition in FEF, PP and EP

This thesis is an attempt to synthesize these three anticipatory frameworks for the purposes of identifying different forms of enrichment and thereby shedding light upon strong life-mind continuity. Having provided descriptions of FEF, PP and EP, I would now like to flag a potential worry that might seem to stand in the way of using these frameworks together consistently: “how can the fundamental role of generative models in PP and FEF be reconciled with the fact that EP rejects the use of inner models in its explanation of perception-action?”. This thesis avoids this worry because rather than endorsing all the theoretical commitments of EP wholesale, I will use some of EP’s commitments and motivations instrumentally as a means of teasing out *ecologically informed* explanations where such explanations can be used. Thus, a priority will be given to the various commitments of FEF and PP with respect to models; generative models will be taken as an essential feature of cognition (and life). However, where aspects of cognition can be accounted for by the role of agent-environment coupling, thus lessening the need to engage highly complex models and/or decoupled processing (but not doing away with models altogether), EP's conceptual apparatus will be deployed. This should be welcomed because "the best ways to minimize long-term prediction error will often be both frugal and action-involving" (Clark, 2016a, p. 191). Importantly, one from the perspective of PP and FEF must not be committed to the thesis of direct perception to use EP's apparatus. As such, the worry that these frameworks cannot be consistently used together given their different commitments to models only arises when endorsing each framework wholesale, something which this thesis will not do.

0.8 The Primary Question of the Thesis Revisited

With this understanding of the three anticipatory frameworks in hand, let us now return to the primary question of this thesis:

> What kind of insights about the strong continuity of life and mind do the Free Energy Framework, predictive processing and ecological psychological framework collectively provide?

Given the anticipatory natures of FEF, PP and EP, and assuming the environmental complexity thesis (ECT) affords a fruitful starting point for the investigation of cognitive systems, we may restate this question as:

> What can our three specific anticipatory cognitive frameworks (FEF, PP and EP) tell us about the underlying organizational principles of both living

> processes and cognitive processes which allow organisms to deal with environmental complexity?

Again, one suggestion that has been hinted at above, and that falls out of our initial characterizations of life and cognition is that both of these processes are anticipatory processes by which an autonomous system continues to actively adapt to fluctuations that it encounters in its environment. Mind via adaptive behaviour ultimately serves metabolism and metabolism serves the continued ability to self-organize (i.e., self-production and self-maintenance of the system boundary). Thus, mind via adaptive behaviour serves the continued ability to self-organize. It is my hope that by attempting to understand strong life-mind continuity through the frameworks of FEF, PP and EP this notion that life and mind are adaptive processes may be supported, sharpened and expanded upon. By deploying these anticipatory frameworks to think about different (yet interrelated) forms that cognition can take, this thesis aims to not only throw into relief common underlying organizational principles and properties of life and mind, but to also investigate the explanatory scope and limits of these frameworks and their combinations to account for biological cognition.

One of the suggestions that this thesis will attempt to motivate via considering these frameworks with respect to strong life-mind continuity is how full-blown PP emerged later in evolutionary history as a result of life's becoming enriched in various manners. The kind of PP underwriting decoupled capacities such as planning, mental time travel, thought, and mental imagery generation will be taken as an end point for cognitive enrichment. FEF, along with some of the core conceptual apparatus from EP, will be used to identify the kind of enriched living processes definitive of cognition prior to this full-blown form of PP. In attempting to understand how PP systems might have evolved from simpler precursors, the current thesis suggests possible cognitive architectural precursors to full-blown PP. The cognitive capacities of these PP precursor systems, which deploy many of the same PP mechanisms but may be lacking others, may be described using

FEF and the apparatus of EP. In identifying where such mechanisms are in place and where they are not, various cognitive transition markers and different manners of dealing with environmental complexity be identified. In chapter 4, a particular case will be made for the claim that environmental demands upon organisms to guide their behaviour according to environmental information that is no longer available, what I call *historical context sensitivity*, accounts for the shift to free-energy minimizing, 'partial' PP architectures to full blown hierarchical PP.

The primary question therefore may be broken down to a series of further questions that each of the chapters contained in this thesis is organized around. One question is how FEF, PP and EP can inform the philosophy of cognitive science as to the possible range of forms that biological cognition takes. Chapter 2 investigates this question by looking at the notion of plant perception and how it may differ considerably from animal perception, while chapter 3 uses FEF to investigate and offer an of account of cognition in multi-organismal (symbiotic) associations. A further question that falls out of the primary question is whether or not ecologically direct perception (i.e., coupling to environmental information) is sufficient to account for the kinds of complex cognitive phenomena that are paradigmatic of human cognition. If EP can provide some conceptual apparatus for understanding how living processes may be enriched in simple living systems so as to rise to the status of cognitive processes, can the framework of EP also be deployed in accounting for complex phenomena such as mental imagery generation (chapter 4) or behaviour that is contextually sensitive to events of the past (chapters 5)? Or do such complex phenomena require a distinct kind of enrichment, representative of transition markers that separate the forms of cognition found in simpler organisms from that found in more complex organisms? In providing answers to these kinds of questions, this thesis will use FEF, PP and elements of EP to construct a logical space for thinking about the degrees of complexity that fall out of strong life-mind continuity.

From the primary question of this thesis it is possible to tease out an important methodological question:

> What would conceptualizing cognition—first and foremost—as a kind of biological process suggest about the manner in which cognitive phenomena should be investigated by cognitive science?

In other words, when considering the fact that cognitive capacities in biological systems have an evolutionary history and that the continued presence of these capacities today suggests that they have contributed to ways of dealing with selective pressures (i.e., environmental complexity), how might the manner in which cognitive science investigates such capacities remain sensitive to these biological facts?[37] It is my hope to illustrate that investigating the primary question of the thesis will suggest an answer to this methodological question. Understanding strong life-mind continuity through the lenses of FEF, PP and EP may help to reveal surprising forms of cognition, the existence of which may suggest that the scope of models of organisms used in cognitive science should be expanded in order to account for the range in the manners in which organisms cope with the kinds of complexity in their econiches (chapter 1). This being said, just how much the methodology of cognitive science should be influenced by understanding cognition as an organizational enrichment of life is a question which this thesis does not attempt to fully answer. More humbly, this thesis may at least provide one reason for the reader to assign value to this question and at most provide a partial resource which may be used to inform a possible answer.

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[37] One answer to this question is manifest in the biogenic approach to cognition developed by Pamela Lyon (2006). More will be said about this approach in chapter 1.

0.9 Summary of Chapters

Although this thesis has been written as a collection of independent and interrelated papers, and as such there is no particular order in which they must be read, I would suggest that the reader proceeds by reading the chapters consecutively. The present thesis begins with a groundwork chapter that sets up the theoretical space in which the remainder of chapters will be situated. The subsequent chapters of the thesis are organized to reflect a progression from simpler forms of cognition (and simpler organisms) and the anticipatory frameworks which are best suited to account for them to more complex forms of cognition in humans and the respective framework(s) that can best account for those forms. This organization hence throws into relief a picture not only of how the apparatus of FEF, PP and EP can be used together to consistently account for various forms of cognitive phenomena ranging from simple to complex but this organization also brings out the limitations of these frameworks; it makes explicit how one framework might be deployed in accounting for a particular phenomenon where another one falls short given its theoretical tenets and conceptual apparatus. Finally, I would like to acknowledge that because this thesis has been written as a collection of interrelated papers, there is some repetition from chapter to chapter in the exegesis of various theoretical frameworks being deployed.

Below is a list of the chapters as they are organized and a brief summary of each.

Chapter 1 looks at the biogenic approach to cognition (Lyon, 2006). This kind of approach begins with an understanding of cognition as a biological process and emphasizes the methodological importance of the continuity of mind and life to a complete investigation of cognition. This chapter then turns to a particular worry for biogenic approaches, an example of which is voiced by Fred Adams (2018): by being overly permissive and wrongly identifying sensory processing without intentional content as cognitive processing, the biogenic approach is antithetical to progress in cognitive science. This worry is defanged by firstly looking at some of the *explananda* and actual practices of contemporary cognitive science and showing that this range is consistent with the kind of phenomena which a biogenic approach recognizes as cognitive processes. The second part of this chapter proposes the notion of *a continuum of intentionality* that is defined over the degree to which behaviour is tied to representational content. FEF is used as an illustrative and worked-out example of how a system's weak-intentionality-endowed internal dynamics (i.e., predictions engendered by generative models) give rise to phenotype-constrained adaptive behaviour. Understanding intentionality as both a mark of the mental and as existing along a continuum allows biogenic approaches and approaches that focus primarily on human-like cognitive phenomena to investigate the same overarching process of cognition as expressed in its different forms positioned along this continuum. Whereas one of the forms which cognition takes at one end of the continuum is that of *minimal-perception*, something which will be developed in detail in **Chapter 2**, another form of cognition which occupies the opposite end is that of decoupled mental imagery generation (**Chapter 4**).

Chapter 2 turns from FEF to an FEF-embedded form of PP. The hypothesis of *plant predictive processing* (Calvo & Friston, 2017) suggests that plants, by minimizing prediction error, anticipate the perceptual states they need to occupy to remain in homeostatic balance with the environment. This chapter demonstrates that plant predictive processing when enriched with some of the apparatus of EP can satisfy two independently plausible constraints on perception (i.e., the veridicality constraint and the constancy constraint). It is in the context of this argument that the notion of *minimal-perception* is developed as the active and anticipatory perception of behaviour guiding gradient structure in the perceptual medium. Minimal-perception is contrasted with the kind of 'maximal' perception of objects or gradient sources which is located higher up the continuum of intentionality (**Chapter 1**). It is concluded that, pace our folk-psychological notions of perception, an ecologically enriched plant predictive processing provides a plausible reason to believe that plants engage in minimal-perception and exemplify the strong continuity of life and mind.

Chapter 3 The notion of a physiological individual has been developed and applied in the philosophy of biology to understand symbiosis, an understanding of which is key to theorising about the major transition in evolution from multi-organismality to multi-cellularity. The chapter begins by asking what such symbiotic individuals can help to reveal about a possible transition in the evolution of cognition. Such a transition marks the movement from cooperating individual biological cognizers to a functionally integrated cognizing unit. Somewhere along the way, did such cognizing units simultaneously have cognizers as parts? Expanding upon the multiscale integration view of the FEF, this chapter develops an account of *reciprocal integration*, demonstrating how some coupled biological cognizing systems, when certain constraints are met, can result in a cognizing unit that is in ways greater than the sum of its cognizing parts. Symbiosis between V. Fischeri bacteria and the bobtail squid is used to provide an illustration of this account. A novel, graded, manner of conceptualizing biological cognizers is then suggested. Lastly it is argued that the reason why the notion of ontologically nested cognizers may be unintuitive stems from the fact that our folk-psychology notion of what a cognizer is has been deeply influenced by our folk-biological manner of understanding biological individuals as units of reproduction.

Chapter 4 investigates the degree to which EP, a framework which may be able to successfully account for many aspects of cognitively driven behaviour in simpler organisms (**Chapter 2**), can account for the kind of context sensitive intelligent behaviour paradigmatic of human cognition. To go about answering this question, this chapter looks specifically at affordance perception as developed by Gibson (1979). I argue that although the ecological account of *direct perception* (i.e., explanation without recourse to intervening information processing states) has the conceptual apparatus to explain many of the seemingly difficult cases of affordance context-sensitivity that are studied experimentally, there is one kind of context-sensitivity that ecological direct perception cannot account for: historical context sensitivity. After identifying this explanatory limit of ecological direct perception, it is argued that because PP adapts the ecological notion of affordances, despite its being representationalist about context sensitive affordance perception, PP manages to respect a primary motivation behind direct perception by securing an indispensable role for environmental information exploitation. The explanatory limit of direct perception that historical context sensitivity helps to identify suggests a principled manner of identifying a difference in contextual conditions that maps on to a difference in required PP processing. Here, precision weighting mechanisms start to exert more of an influence on perception-action than would be the case in other instances of affordance perception.

Chapter 5 looks at whether or not and how ‘higher’ forms of cognition can be accounted for by some of the same theoretical apparatus which can account for the forms of cognition occupying the lower areas of the intentionality continuum. Action-based theories of cognition, EP being one of the more stringent forms of which, emphasize the role that agent-environment coupling plays in the emergence of psychological states. *Prima facie*, mental imagery seems to present a problem for some of these theories because it is generally thought to be an environmentally decoupled phenomenon. This chapter, however, argues that mental imagery is much more multifaceted than it seems on the face of it. Focusing on a particular kind of imagery, comparative mental imagery generation, I demonstrate that although such imagery can arise without the need for sensory stimulus as input (it can be what I call “stimulus-absent”) it is also sensitive to ambient stimulus flux; it is what I call “stimulus-sensitive”. That a process is stimulus-sensitive is sufficient for it to qualify as an environmentally coupled process. This chapter contributes to EP by developing the ecological notion of *variant coupling* (i.e., the coupling of a perceptual system to variant environmental information). I argue that variant coupling may not only offer a manner in which action-based theories may account for comparative mental imagery generation, but it may offer a manner of accounting for other forms of imagery also. The chapter concludes by offering a novel taxonomy for online/offline cognitive phenomena that takes the notions of stimulus-absence and stimulus-sensitivity in addition to coupling/decoupling to invariant and variant information into account, showing how the traditional offline/online distinction is inadequate for characterising cognitive capacities and processes.

Author’s contributions

All chapters in this thesis have either been published or are currently under review. Listed below are the existing references for the published papers.

Chapter 1 is currently under review.

Chapter 2 has been previously published as:

Matthew Sims (2019) Minimal-perception: Responding to the challenges of perceptual constancy and veridicality with plants, *Philosophical Psychology*, 32:7, 1024-1048, DOI: 10.1080/09515089.2019.1646898

Chapter 3 has been accepted for publication:

Matthew Sims (2020) How to Count Biological Minds: symbiosis, the Free Energy Principle, and reciprocal multiscale integration, *Synthese* (forthcoming).

Chapter 4 is currently under review.

Chapter 5 has been previously published as:

Matthew Sims (2019) Coupling to Variant Information: An Ecological Account of Comparative Mental Imagery Generation, *Review of Philosophy and Psychology*, https://doi.org/10.1007/s13164-019-00454-9

Chapter 1

A Continuum of Intentionality: linking biogenic and anthropogenic approaches to cognition

Abstract

Biogenic approaches investigate cognition from the standpoint of evolutionary function, asking what cognition does for a living system and then looking for common principles and exhibitions of cognitive strategies in a vast array of living systems – non-neural to neural. One worry which arises for the biogenic approach is that it is overly permissive in terms of what it construes as cognition. In this paper I critically engage with a recent instance of this way of criticising biogenic approaches in order to clarify their theoretical commitments and prospects. In his critique of the biogenic approach, Fred Adams (2018) provides a strict demarcation criterion that uses the presence of intentional states with conceptual-level representational content to identify cognitively driven behaviour. In this paper I propose to grant Adams' contention that intentionality is a mark of the cognitive, but I argue that this is compatible with endorsing the biogenic approach. I argue that because cognitive science is not exclusively interested in behaviour driven by intentional states with the kind of content Adams demands, the biogenic approach's status as an approach to cognition is not called into question. I then go on to propose a novel view of intentionality whereby it is seen to exist along a

continuum which increases or decreases in the degrees that behaviour is tied to representational content. Understanding intentionality as existing along a continuum allows biogenic approaches and anthropogenic approaches to investigate the same overarching capacity of cognition as expressed in its different forms positioned along the continuum of intentionality.

1.1 Introduction

One kind of starting point for investigating cognition begins by asking questions pitched at the kind of ‘high-level’ capacities paradigmatic of human cognition (e.g., beliefs, desires, concept formation, language, reasoning, conscious experience, etc.): What is the relationship between perception and belief? How does a child learn the concept of a “bird”? Is attention necessary for consciousness? This starting point then attempts to account for possible instances of such ‘high level’ capacities within an explanatory framework tailored specifically to them. From this *anthropogenic* starting point, human cognition is the standard against which all other forms of behaviour are recognized as a proper topic for cognitive scientific inquiry. Another kind of starting point, the *biogenic approach* (Lyon, 2006) begins investigating cognition from the evolutionary assumption that ‘higher’ cognition, like other biological capacities, has evolved from simpler cognitive (or cognition-like) capacities. Under the evolutionary assumption, cognition, like forms of breathing, may have evolved many times over the course of evolutionary history. The biogenic approach (BA) as such starts with biological facts and attempts to work its way up to human cognition. By widening the scope of model organisms under consideration to include organisms such as bacteria and plants as cognizers, proponents of BA suggest that it is well placed to identify possible unifying principles and conserved mechanisms underlying a full range of cognitive capacities, from simple to complex (see Lengler et al., 2000; Ben Jacob et al., 2006; van Duijn et al., 2007; Baluška & Mancuso 2009; Bechtel, 2014; Barrett, 2019; Calvo et al., 2020).

One worry which arises for BA is that it is overly permissive in terms of what it construes as *bona fide* cognition. The behaviour of bacteria and plants is something that philosophers have been prone to consider as an inflexible, reflexive response to sensory stimuli (Dennett, 1984; Sterelny, 2001; Godfrey-Smith, 2002; Schlicht, 2018). If such behaviour under BA qualifies as an expression of cognition, then it seems—one might worry—that the very notion of cognition is rendered too unconstrained to be explanatorily useful. This kind of worry is voiced by Fred Adams (2018), who in a recent critique of BA responds by providing a strict demarcation criterion that allows for drawing a sharp line between the cognitive and the non-cognitive. This classification methodology, which is informed by traditional philosophy of cognitive science, uses the presence of intentional states with conceptual-level content as a manner of picking out behaviour that is underwritten by cognitive processing. Armed with this conception of the mark of the cognitive, Adams mounts an argument against BA: because the various cases of behaviour that biogenic theorists have classified as cognitive are not underwritten by intentional states with conceptual-level content, such cases of behaviour fail to be expressions of cognition; they are more accurately classified as hardwired responses to sensory information processing. What I call Adams' 'argument from intentional content' goes on to conclude that this conflation is harmful to the endeavours of cognitive science and that BA should be abandoned as an approach to cognition.

The general worry that BA is overly permissive (or even incoherent) relies on an implicit appeal to some mark of the cognitive. Adams is thus useful to engage with because he makes a rare attempt to explicitly spell out what this mark of the cognitive is, in a way that purports to be informed by the nature and methodology of cognitive science. Identifying the infelicities of Adams' critique gives us a better view of the explanatory tools that BA might have at its disposal, and the manner in which anthropogenic and biogenic approaches relate to each other. Is there, however, another classification methodology available that is compatible with the range of cognitive behaviours recognized by biogenic theorists, yet which nonetheless offers a manner of distinguishing the cognitive from the non-cognitive? In what follows, I will argue in favour of an affirmative answer to this question.

For the purposes of this paper, I propose to grant Adams' contention that intentionality is a mark of the cognitive, but I argue that this is nonetheless compatible with endorsing BA. I do so by proposing and arguing for the *intentionality continuum thesis*, a thesis that is informed by looking at the range of projects cognitive scientists actually spend their time doing. On one end of the taxonomy I present there is *weak intentionality* of the internal dynamics that drive sensorimotor and biochemical behaviour. Meaningful content at the level of weak intentionality is, we shall see, phenotype-dependent. It is directed at sensory states that are to be pursued (or avoided) given the conditions which an agent must remain in in order to preserve its organization over the long run. On the other end there is *strong intentionality* which involves internal representations with conceptual content and possible phenomenological character that is deployable offline. Intentionality is a necessary feature of cognition, but where a particular behaviour/state falls upon the continuum of intentionality is of no relevance to that behaviour's being (or not being) an expression of cognition. I shall argue Adams' anthropogenic-based hallmark of the cognitive looks arbitrary once we appreciate that the intentionality that is of interest to cognitive scientists is not exhausted by intentional states with truth evaluable content. Given that contemporary cognitive science does indeed investigate and recognize putative cognitive phenomena and mechanisms that fall all along the continuum of intentionality, the manner in which Adams delineates cognitive from non-cognitive processes is undermined by the range of interests and aims of researchers in the very discipline he attempts to safeguard. Understanding intentionality as existing along a continuum allows biogenic approaches and anthropogenic approaches to investigate the same overarching capacity of cognition as expressed in its different forms positioned along the continuum. The continuum thesis is promising not only as grounds for a reply to cognitive chauvinists who use an overly sophisticated notion of cognition, but because it illustrates that both biogenic and anthropogenic approaches are valid starting points for investigating a common notion of cognition.

This paper will proceed as follows: *Section 1.2*, provides an overview of BA. In *Section 1.3*, I present Adams' argument from intentional content against BA. In *Section 1.4*, after quickly surveying some of the practices and projects of contemporary cognitive science, I argue that because cognitive science is not exclusively interested in behaviour driven by intentional states with truth evaluable representational content, BA's status as an approach to cognition is not called into question in the way that Adams suggests. I then propose a novel view of intentionality whereby it is seen to exist along a continuum which increases or decreases in the degrees that behaviour is tied to representational content. I make use of some of the conceptual apparatus of the Free Energy Framework to illustrate the kind of 'weak intentionality' that arises at the initial end of this continuum. This section concludes by returning to the worry that BA is overly permissive. I argue that the worry is defanged when it is recognized that there may be living systems that do instantiate weak intentionality and that cognition, even if widespread, takes many forms. This being said, sharpening the concepts that delineate the various forms of cognition that are located along the continuum of intentionality will be central to the continued progress of any biogenic approach to cognitive science.

1.2 The Biogenic approach

In her seminal paper ‘The biogenic approach to cognition’ Pamela Lyon (2006) identifies a particular investigatory strategy which she claims has been central to two distinct kinds of cognitive explanation: *self-organizing complex systems theories* and *autopoietic theory*. The first of these kinds of explanation, examples of which may be seen in the work of Goodson (2003), Rosen (1985), Piaget (1970), Popper (1965/1972), Vertosick (2002), Christensen (2004), Bickhard (2009), and Deacon (2012), among others, places emphasis upon the relation between cognition and the second law of thermodynamics. More precisely, it sees cognition as a process that underwrites an organism’s ability to remain in thermodynamically improbable non-equilibrium steady states despite the tendency for all systems to move towards thermodynamic equilibrium. Homeostasis, the preservation of steady-states (e.g., physiological states such as oxygenation, core temperature, and metabolic energy levels), is an ongoing result of a dissipative system’s ability to modulate its parameters (i.e., internal processes and external behaviour) so as to avoid persistence-compromising situations (e.g., starvation or predation).[38] Self-organizing complex systems theorists thus see cognition as the host of capacities, varying in their complexity, that guide a system’s parameter modulation so as to preserve its homeostatic balance and keep it at thermodynamic disequilibrium despite environmental perturbance.

In contrast, rather than understanding cognition in terms of thermodynamic regulation, autopoietic theory (Maturana 1970/1980; Maturana & Varela,1980;

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[38] A dissipative system is a thermodynamically open system that, which in virtue of exchanging matter and energy with the environment, remains far from thermodynamic equilibrium.

Thompson, 2007; Di Paolo, 2005) understands cognition in terms of a biological system's ability to continuously produce itself and distinguish itself from its milieu.

Self-production is the internally driven process whereby a biological system continuously constructs and realizes its own network of processes (Maturana and Varela, 1980).[39] *Self-distinction*, on the other hand, is the process of generating and preserving systemic boundaries (e.g., a cell membrane) by which an organism partitions itself from its non-systemic environment. Self-production and self-distinction are construed as necessary and sufficient conditions on life. According to autopoietic theory, cognition is entailed by life, expressing a deep continuity between life and mind. In other words, "living systems are cognitive systems, and living as a process is a process of cognition" (Maturana & Varela, 1980, p. 13).[40] The overlap between self-organizing complex systems theory and autopoietic theory should be clear: both kinds of theory construe cognition as a biological adaptive strategy; cognition is expressed in a set of adaptive behavioural capacities which *functionally* underpin a biological system's ability to remain alive. Self-organizing complex systems theory emphasizes capacities to navigate energetically dynamic environments so as to self-preserve; autopoietic theory emphasizes the capacities leading to self-production of the organismic boundary that defines the autonomous organism in relation to its external environment.

This overlap is illustrative of the core explanatory strategy of BA; BA starts from the notion that cognition is a functional capacity that, being driven by various selection pressures, has been gradually selected for—perhaps many times—over evolutionary timescales. Thus, BA starts with the facts of biology in attempting to

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[39] There are important disagreements between 'autopoietic theory' as propounded by Maturana and the enactive approaches developed by Varela, Thompson and Di Paolo. See Villalobos & Ward (2015).

[40] Although autopoietic theory is an example of a biogenic explanatory approach, it is not required that a biogenic approach be committed to the kind of entailment thesis (i.e., that life entails mind and mind entails life) that is central to autopoietic theory. The entailment thesis, for example, is not held by self-organizing complex systems theories.

understand *what cognition does for biological systems*. This is clear when Lyon writes:

> "An investigator adopting a biogenic approach assumes that the principles of biological organization and the requirements of survival and reproduction present the most productive route to a general understanding of the principles of cognition. Cognition, whatever it may be in the future, is naturally a biological process and a biological function" (2006, p.12).

We saw above that BA may be contrasted with the anthropogenic approach (AA) (Lyon, 2006). This latter approach may be understood in terms of two related claims. The first claim is that the most fruitful starting point to the investigation of cognition in general as it is found in nonhuman animals and other lifeforms is understanding human cognition. The second claim is one of demarcation: the cognitive is demarcated from the non-cognitive by using distinctively human capacities (e.g., believing, thinking, planning, decision making, reasoning, etc.) as the non-negotiable standard of cognition. The notion of cognition that these kinds of capacities and their putative mechanisms suggest is then used comparatively to determine whether or not the behaviour of non-human systems should be considered as expressive of cognition. With these two moves, AA works from the human case "downwards" to possible cases of non-human cognition (Lyon, 2006). Because of its human-centred demarcation criteria, AA generally assumes that the possession of a central nervous system, the use of representational states, and rationality are all central features of cognition.

In contrast, by seeing the evolutionary function of cognition as the proper starting point of investigation, the biogenic theorist may choose to investigate how that function is expressed in humans as well as in bacteria depending upon the theorist's interests. As such, BA's proponents argue that since it recognizes human cognition as being a determinate of a larger determinable category 'cognition', the biogenic perspective allows for a more complete picture of what cognition does for living systems and how various cognitive phenomena are related despite being selected for by different evolutionary pressures. Lyon writes:

> “It is important to stress that the two approaches are not mutually exclusive, indeed, both are necessary for a complete picture. We must understand what cognition is and what it does as a natural phenomenon, but we also have to understand human psychological experience” (2006, p. 26).

Here, Lyon makes it explicit that the two approaches to investigating cognition are complementary; investigating what cognition does for biological systems will ultimately include investigating how it does what it does in the human case. That being said, there is a tension between AA’s demarcation criterion and BA’s biological starting point. For BA, many genuine instances of cognition may take a very different form than that of human cognition. It is due to the AA theorist’s more restrictive conception of cognition that she may attempt to dismiss the broader set of non-human-like capacities recognized as cognitive by BA theorists as something else. As will be seen in the next section, it is just this kind of charge that Fred Adams foists against BA.

1.3 The Argument from Intentional Content

Adams (2018), on behalf of AA, has recently raised an objection against BA. Appealing to the interests and practices of contemporary cognitive science, he argues that cognitive scientists use the term “cognition” to refer to something very different than what BA theorists use the term to refer to. Hence, thinks Adams, attending to cognitive scientific practice shows that we should prefer AA to BA. In line with a venerable trend in philosophy of cognitive science (Fodor, 1990;

Dretske, 1981), Adams's general anthropogenic classification methodology distinguishes cognition from non-cognition by holding that the former is a kind of processing that necessarily involves internal representational states with intentionality. Intentionality, the property of "aboutness" that mental states have to be directed at the world was originally proposed by Brentano (1874/1995) as the mark of the mental. In other words, "all and only mental phenomena exhibit intentionality" (Schlicht, 2018, p. 8). These intentional states, Adams contends, take the format of representations with conceptual-level content, the meaning of which is determined by states of affairs in the world that they are about. Adams writes:

> "[…] cognition requires specific kinds of representational formats. And these formats are built on top of information processes. The symbols that are cognitive are built from information exchanged between system and environment. But the format of these representations is *semantic* at a level above that of the information itself" (Adams, 2018, p. 24; my emphasis).

It is only when intentional states with conceptual-level content operate on sensory representations (i.e., sensory information states) that the resulting behaviour can truly be said to be cognitively driven.[41] Adams's clarifies this format distinction between meaning-bearing representations with conceptual-level content and sensory representations when, referring to his own work and that of Dretske (1981,1998) he writes:

> "But conceptual representations are different kinds of representations than sensory ones. The change from information to meaning (where the content of a concept is its meaning) involves changes in the format of representation" (Adams, 2018. 28).

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[41] The mere deployment of representations with intentional content without resulting behaviour (e.g., thinking, reasoning, etc.) or in the absence of sensory information states would also qualify as cognitive according to Adams.

And again

> "I am suggesting that cognition is this kind of information processing which alters the representational format to a different level—to the level of meaning and not just information" (Adams, 2018. 28).

To get an idea of the kind of representational format that he argues underwrites genuine cognition, Adams offers an example. If a person senses that the temperature of a room is increasing, whether or not she is aware of it, she also senses the increasing mean molecular kinetic energy (mmke) of the air surrounding her. However, if she thinks that the room's temperature is increasing, she needn't think that the mmke of the surrounding air is also increasing. This example demonstrates that although thoughts, beliefs, desires, and other representations with intentional content may be about the same referent (in this case a target event), thinking one kind of thought (distinguished by its meaning) about a referent does not entail thinking all corollary thoughts about the same referent. Although sensory information processing may involve representations, such representations fail to have the right format, on Adams' construal, and thus they never to rise to the level of meaning.[42]

In contrast to the deployment of intentional states with conceptual-level content, Adams claims that what BA calls 'cognition' is mere information processing of sensory states which results in hardwired, adaptive behaviour. Although cognitive and non-cognitive processes both involve information processing and adaptive

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[42] The distinction between what Adams calls sensory representations and representations with intentionality may be interpreted as being analogous to Grice's (1957) distinction between "natural meaning" and "non-natural meaning". Natural meaning is indication-based. For example, smoke indicates fire, but smoke is not *about* fire in the sense that one cannot intelligibly speak about the presence of smoke in the absence of fire as something that is 'false'. Non-natural meaning, on the other hand, rises to the level of semantics. For example, that the word "water" means "tasteless, odourless, colourless liquid" makes it the case that the proposition "water is black and tastes like tar" is false.

behaviour, the kind of adaptive behaviour that is driven by mere sensory information (in a sensory format) alone does not rise to the status of being cognitive behaviour. It is because what biogenic theorists refer to as cognition is actually "information-driven behaviour that is adjusted in response to variable environmental conditions" (Adams, 2018, p.27), that biogenic plant scientists and biologists erroneously categorize the adaptive behaviour of organisms such as plants and bacteria as cognition-driven processes. When biogenic theorists claim that plants and bacteria exhibit cognitive capacities what they are really doing is changing the subject altogether from cognition to something else. For in such cases "there are no internal states that mean (in the sense of having truth values) things outside the system" (Adams, 2018, p.29). Adams concludes that because intentionality is a distinctive characteristic of the cognitive and this is something which BA by ascribing cognition to plants and bacteria fails to respect, biogenic researchers are in the practice of investigating something very different than what cognitive science recognizes as cognition.

I will now respond to this argument by providing another classification methodology for distinguishing the cognitive from the non-cognitive, one which is compatible with the range of cognitive behaviours that BA recognizes.

1.4 Responding to the Argument from Intentional Content

It may be assumed that Adams's primary reason for locating cognition at the level of intentional states with semantic content is based upon his view of what cognitive science recognizes as cognition.[43] If biogenic theorists when ascribing cognition to

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[43] To be clear, Adams is in agreement with Lyon, who when setting out what she identifies as the core anthropogenic principles (i.e., the core principles of contemporary cognitive science), claims that intentionality is a distinctive feature of cognition according to AA. BA principles as put forth by

bacteria and plants are using "cognition" to mean something other than processing that reaches the level of intentional states with conceptual-level content "then no one in current cognitive science would be alarmed" (Adams, 2018, p.28). However, if such theorists are not ascribing cognitive capacities to plants and bacteria instrumentally and actually "intend the cognitive ascriptions to be true, then it is not harmless" (Adams, 2018, p.29). I will now demonstrate that proponents of BA can both agree with Adams that intentionality is a distinct feature of the cognitive and yet consistently reject his claim that intentionality must be concept-based in order for processing to qualify as cognition. More specifically, using a classification methodology that takes what cognitive scientists actually do as its lead, I shall propose a view of intentionality that conceives of it as a continuum, ranging from weak to strong intentionality. Because cognitive science investigates and recognizes cognitive phenomena all along the continuum and not just at the level of strong intentionality where Adams restrictively locates cognition, his argument against BA turns out to be ill-motivated. In locating cognition exclusively at the level of strong intentionality, Adams disregards the range of research that cognitive scientists have engaged in over the course of the last 40 years. I begin with an initial response that considers some of the current practices of cognitive science. I shall then introduce the intentionality continuum thesis as a primary response to Adams' argument from intentionality and more generally as a ground for rejecting the kind of cognitive chauvinism that Adams' argument is representative of.

Lyon do not include intentionality. Interestingly, if the continuum that I propose below is correct then Lyon has overlooked intentionality as a necessary feature of cognition that is common to BA and AA.

1.4.1 The Practices of Current Cognitive Science

Does cognitive science recognize and investigate only those phenomena that are underwritten by intentional states in the form of beliefs and desires with concepts as their constituents? While there is plenty of cognitive science that is aimed at investigating phenomena at the level of Adams' strong intentionality, it appears that there is plenty that is not. A wide range of cognitive scientific research programmes such as action-blindsight research (Kentridge, Heywood & Weiskranz, 1999), two visual streams research (Milner and Goodale, 1992), 4E cognition (i.e., enactive, embedded, embodied and situated cognition) (Clark, 1997/2008; Chemero, 2009; Beer 2000; Thompson, 2007; O'Regan, 1992; Lakoff & Johnson, 1980; Kirsh, 2010), action-oriented cognition (Jeannerod, 2006; Cisek & Kalaska, 2010; Engel, Maye, Kurthen, & König, 2013; Pezzulo, 2011; Tversky, 2019), and dynamic systems accounts (Thelen & Smith, 1994; Beer, 2000; Kelso, 2016; Newell & Liu, 2012)–to name a few–investigate and explain psychological processes in ways that do not essentially implicate states with conceptual-level contents. This is not to deny that much of cognitive science is focused upon phenomena at the level of strong intentionality. What I am arguing however is that cognitive science does not *exclusively* investigate phenomena at the level of strong intentionality. The existence of each of these many programmes demonstrates that cognitive science recognizes and investigates processes that do not exclusively involve conceptual representations. To take an example, the core of embodied cognition is based upon the claim that a complete understanding of cognition requires understanding the various constitutive roles that the sensorimotor systems play in not only conceptualization (see Lakoff and Johnson, 1980) but also how we respond to environmental changes and solve problems in the here and now (Clark, 2008). A classic example of this is the ecological solution to the baseball outfielder problem in which by moving so as to keep a flyball's position steady in one's field of view—–staying coupled to it via sensorimotor engagement–—one is able to adjust one's movement's in light of the ball's perceptible trajectory and eventually catch it (McBeath et al., 1995).[44] The kind of conceptual-level representation that Adams argues is definitive of intentionality is rendered superfluous by this simple solution to the problem of how to catch a fly ball.

More generally, the kind of cognitive science which has emerged in the last 40 years has recognized a problem space that calls for the use of adaptive strategies that are not limited to detached planning, abstract thought, and conceptualization. The agreed problem space of cognitive science has been widened to include problems that arise on faster timescales. Attempting to address these problems has motivated many researchers to abandon the kind of traditional "sandwich" model of cognition that Adams uses (i.e., where cognition is conceived of as a process occurring sandwiched between perceiving and acting).[45] Many of the problems in this wider problem space may be efficiently solved by eliciting frugal and fast solutions of environmentally coupled perception and action loops (Clark, 2008). This is not to say (radically) that all solutions required within this widened problem space involve the coupling of an organism to the environment via action and perception, but rather that there are various kinds of cognitive strategies that may be deployed given the nature of the problems which organisms are faced with.

Adams' argument from intentionality would like to conclude that BA is untenable and is harmful to cognitive science because it conflates actual cognition with mere sensory information processing. However, if one takes into account the range of research programmes that have been developing over the last 40 years (i.e., what cognitive scientists have actually been investigating and how the field is developing), his claim about what "cognition" means to cognitive science is simply

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[44] For different theoretical perspectives regarding this process see McLeod, Reed & Dienes, (2006) on optical acceleration cancelation and see McBeath, Shaffer & Kaiser, (1995) on linear optical trajectory.

[45] Susan Hurley (1998) is responsible for coining the term "sandwich model".

not true (anymore). Adams hence fails to provide a valid reason to reject BA as a *cognitive* explanatory framework. This being said, the argument from intentionality does however provide a valuable opportunity to demonstrate just how BA and AA are linked across a continuum of intentionality. Disagreeing with Adams about BA doesn’t entail rejecting the idea that intentionality is a distinctive feature of cognition. It does, however, require understanding more about the relationship between the kind of conceptual-level intentionality Adams emphasises and what is implicated in the self-organising/autopoietic dynamics of BA.

In the next subsection I will develop the intentionality continuum thesis and argue that when taking it into account, demarcating the cognitive from non-cognitive by way of an intentionality criterion fails to be a consideration against BA. If the intentionality continuum thesis is correct, BA and AA merely lie upon two poles on the continuum, separated by the degree of intentionality involved in the kinds of cognitive phenomena they investigate. I will now introduce the crucial notion of weak intentionality that underlies all degrees of intentionality on the continuum and is a common thread in the two BA explanations previously canvased in Section 1.2.

1.4.2 The Intentionality Continuum Thesis: weak intentionality

On one end of the intentionality continuum is what I call *weak intentionality*. I shall define this as the phenotype-relative aboutness of internal dynamics that is directed at target objects/environmental state changes (e.g., gradients) and which causally underpins adaptive behaviour. Such dynamics are meaningful insofar as they guide an organism’s interactions with its relevant environment or *Umwelt* (von Uexküll, 1957), allowing it to remain in the select set of physiological (viable) states that are defined by its phenotype.[46] Importantly, although these dynamics allow homeostatic maintenance, as we shall see below, they are not reducible to the kind of closed loop feedback control involved in maintenance of homeostatic states.

Much like what the autopoietic theorists have called “basic intentionality” (Thompson, 2007; Schlicht, 2018), weak intentionality is a feature of the entire organism and its behaviour rather than a feature of cognitive states or underlying mechanisms. Weak intentionality is a property of an organism’s integrated internal dynamics that is *causatively manifested in sensorimotor and biochemical behaviour*. Given the integrated nature of these dynamics, not just any behavioural response counts as weak-intentionality-driven. In order to qualify as such behaviour must be directed at having higher-order homeostatic influence; an organism invests its current short-term homeostatic stability (i.e., metabolic resources) for anticipated long-term homeostatic stability brought about as a result of that investment. In some organisms, this will be manifest as overt behaviour, exerting a direct influence upon its surrounds (e.g., spending metabolic resources now in cutting timber and building a fire to avoid freezing over the night). In other organisms, this higher-order influence may take the form of metabolically expensive investments in gene transcription in preparation for yet-to-be-encountered stress conditions (see below for an example).

One primary distinction between autopoietic basic intentionality and weak intentionality is that where the former may be understood as non-representational, the latter is representational but in an undemanding way. Representation at the level of weak intentionality is compatible with the idea that biological systems detect rich environmental information to perceive their surrounds and direct their

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[46] Similar to the notion of meaning underwriting J.J. Gibson’s (1966,1979) ecological notion of *affordances* (i.e., perceivable organism-relative opportunities for action that the environment offers) the meaning expressed in weak intentional content is not something that may be divorced from either the (anticipated) structure of the environment or the (anticipated) states of the biological system.

behaviour (Gibson, 1966, 1979; Michaels & Carello, 1980). This is because the function of these representations is not to mediate an organism's epistemic contact with the world or to be accurate proxies of their target states but rather to *poise* the entire biological system for adaptive interaction with meaningful aspects of its environment. The upshot of this poise is that an organism's integrated sensorimotor (and biochemical) behaviour is continuously driven towards anticipated outcomes brought about by that very behaviour (e.g., chemical gradient increases that specify the distribution of food). These outcomes reflect the conditions under which that kind of organism can successfully continue to preserve itself under selective pressures. In other words, the poising representational activity at the level of weak intentionality—when all goes well—may be inaccurate but nonetheless deliver satisficing results in the form of survival.

Representation at the level of weak intentionality may be conceptualized in terms of two different content-related aspects: weak intentional content is both future-oriented and action-oriented. Content is *future-oriented* in that it is anticipatory of environmental and sensory state changes which would occur were *such and such* a behaviour initiated given current environmental states. These future-oriented dynamics are tantamount to the occasioning *of subpersonal predictions* that (via sensorimotor or biochemical behaviour) mandate the temporary alteration of homeostatic equilibrium *now* (action) in order to avoid anticipated irrecoverable deviation from homeostatic equilibrium *later*.[47] Such predictions arise in virtue of the fact that a living system embodies a model of itself thriving in its environment; because all living systems that exist are the result of an evolutionary history of organism-environment interactions, any existing organism's anatomy, physiology and behaviour has been 'tuned' to its environment, capturing the very conditions under which it can metabolically function (i.e., its viable state range). These conditions take the form of stable expectations that are the standard against which

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[47] For example, your expending a lot of precious metabolic energy now (i.e., swimming as fast as you can to reach the shore) is a temporary deviation that might allow you to avoid being eaten by a hungry shark.

all environmental perturbation is measured; they govern both when and how a system compensates for possibly damaging deviation from the evolutionary norms they capture. Future-oriented content allows some systems to act before deviation from the norms it embodies has occurred.

For example, after detecting decreasing levels of its preferred nutrient (glucose) in its environmental medium, some strains of wild yeast, *Saccharomyces cerevisiae*, begin the metabolically expensive process of galactose utilization pathway induction, allowing them to catabolize galactose in preparation for *eventual* glucose depletion (Wang et al., 2015).[48] One manner of understanding this phenomenon is that the internal dynamics that facilitate galactose utilization pathway induction are modified in part by the yeast's sensitivity to a tendency in the global structure of its environmental medium (i.e., decreases in glucose concentration specify the eventual exhaustion of glucose). This modification biases the system to behave anticipatorily, acting not solely with respect to its short-term homeostatic maintenance and the sensory/environmental states that it is currently detecting (which otherwise might be considered a mere reflex-like response) but with respect to its homeostasis over the long-run and the sensory states that it is likely to encounter given the kind of model it embodies (i.e., the kind of organism it is).[49] Given that *S. cerevisiae* has the stable expectation "I am

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[48] Wang et al. (2015), write: "We now have shown that low or decreasing levels of a preferred nutrient can serve as a predictive cue for eventual depletion. Since this is inevitable when cells deplete a mixture of nutrients at unequal rates, and mixed-nutrient environments are ubiquitous in nature, environmental anticipation may be a more widespread regulatory strategy than previously recognized" (p.16).

[49] An important difference between sensorimotor (or biochemical) behaviour driven by weak intentional content and mere reflex-like response is that the former necessarily has a degree of flexibility whereas the latter may be reducible to homeostatic control loops. Reflex-like control loops drive responses to stimuli in virtue of sensory deviations from genetically encoded, 'expected' setpoints (i.e., *constant* predictions that describe a limited range of values that states can take and remain conducive to the viability of the system). See Pezzulo et al., (2015). Flexible behaviour on the other hand (minimally) requires a level protracted (i.e., longer timescale) systemic integration of sensory pathway information on the part of the behaving system, allowing for context sensitive anticipatory response to future global changes in that system's external and internal environment. Thus, future-oriented, weak intentionality-driven behaviour is 'for'

always in a nutrient rich environment", it will behave in ways that make its soon-to-be-encountered environment fit this expectation by inducing the galactose pathway. This expectation is a state of the whole organism, manifesting itself in a higher-order homeostatic influence.

The fact that content is future-oriented exposes a further important fact: weak intentional content has a degree of independence from the influences of the environment. This degree of independence frees behaviour from being fully determined by the current states of the encountered environment; it opens up a space for a kind of primitive agency and motivation; rather than being "pushed around" by sensory stimuli, an agent's behaviour is normatively constrained by maintaining certain long-term homeostatic steady-states that its persistence depends upon.

Relatedly, representational content at the level of weak intentionality is *action-oriented* (Clark & Toribio, 1994; Clark, 1997; Tschantz, 2020); it does not merely describe environmental/sensory states but imperatively guides action so as to bring preferred environmental/sensory states about. The descriptive content of the internal dynamics that cause the galactose utilization pathway to be induced may be something like "there will be an absence of local glucose in the near future, given the decreasing gradients of local glucose currently and in the immediate/near past"; the imperative content may be "start inducing the galactose utilization pathway now!". [50] One characteristic of this action-oriented aspect of representational content that is particular to the level of weak intentionality is that it is action guaranteeing. In other words, where there is weak intentional content, action follows as a result.

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homeostatic maintenance but is not itself homeostatic maintenance. It corresponds to allostatic control.

[50] Misrepresentation in this example may be understood as a case in which the induction of the galactose pathway occurs due to a small decrease in the sensed glucose concentration despite the overall tendency of the environment to be glucose abundant.

This notion of weak intentionality is implicated in BA. Recall that in both autopoietic theory and self-organizing complex systems theory cognition is conceptualized functionally in terms of those adaptive behavioural capacities underwriting a system's viability maintenance. In order for behaviour to be adaptive it must be constrained in ways that are adequate to the viability of the kind of living system in question. It is only by being so constrained that behaviour qualifies as cognitively driven. The answer to the important question of "what constrains behaviour in ways that makes it adaptive for a particular system?" exposes how weak intentionally is implicated in BA. In self-organized complex system theory, it is in virtue of a system's embodying an anticipatory model of itself and its environment (i.e., the states that define it physiologically) (Rosen, 1985/2012; Goodson, 2001) that its adaptive behaviour is appropriately constrained.[51]

In autopoietic theory, the same important question may be approached from a different angle by asking: How does a system distinguish autopoietic-relevant from autopoietic-irrelevant objects/environmental state changes that it should interact with? Because the domain of autopoietic-relevant objects/environmental states that one interacts with *is* the "domain of the cognitive" (Maturana, 1980), answering this question addresses the question of what constrains cognitively driven behaviour. According to autopoietic theory, a system's adaptive (and hence cognitively driven behaviour) is constrained by its organization. Organization may be understood as the stable dynamics of a system that defines it as the system it is and which, unlike its physical structure, cannot change without the system's ceasing to be. Adaptive behaviour, according to both self-organizing complex systems theory and autopoietic theory, is thus constrained by the subset of a system's internal dynamics (i.e., its model or its organization) that capture the kinds of objects/environmental state changes that are relevant to its continued survival. It should be clear by this point how weak intentionality is related to this account of

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[51] For a self-organizing complex systems theory account of anticipatory cognition that rejects internal anticipatory models in favour of models that are physically embodied in a system's dynamics see (Riegler, 2001).

cognition: weak intentionality follows from the fact that the activity of models and/or systemic organization is directed at those environmental conditions, the bringing about of which supports the continuation of that very model and/or organization; adaptive behaviour in BA is constrained by internal dynamics that, in virtue of their capturing phenotypic norms, are endowed with weak intentionality.

An illustrative and worked out example of the kind of weak-intentionality-endowed internal dynamics in place in BA is provided by *the Free Energy Framework* (Friston, 2010, 2012; Friston & Stephan, 2007) and its notion of *generative models*. The Free Energy Framework is a powerful unifying framework in neuroscience and biophysics, in which both life and cognition (e.g., action, perception and learning) are explained in terms of the same fundamental imperative to minimize free energy. Free-energy is an information theoretic quantity that measures the difference between the sensory states that an organism expects itself to observe given its generative model and the sensory states that it actually observes. From a statistical perspective, a generative model may be cast as a network of highly integrated, ‘beliefs’ (i.e., joint probability distributions) that biophysically encode the causal structure of the environment that an agent should encounter (given its phenotype) and the effects of action on that causal structure. They are entailed by both the continuous (subpersonal) prediction of sensory states that any phenotype-specific organism should expect itself to be in (e.g., a fish should continuously embody predictions that it is in water rather than on land if it is to survive) and the effects of its actions on the world and hence on its own sensory states. It is by bringing about the environmental causes of its own preferred sensory states that a biological system reduces the discrepancy between the phenotypic norms encoded by its generative model and the sensory states it observes. Weak intentionality in this context is none other than the phenotype-relative aboutness of the predictions engendered by the generative model that constrain free-energy minimizing behaviour. It is because an organism and its behaviour entail the kind of generative model that it does that the predictions answering to that generative model have the organism-relative, biologically normative content that they do.

1.4.3 From Weak Intentionality to Strong Intentionality

Located on the opposite end of the intentionality continuum is the kind of intentionality that Adams identifies as a distinctive feature of cognition. Strong intentionality may be characterized as the *aboutness of mental states* rather than the aboutness of behaviour-driving internal dynamics of the organism. It is at this level of intentionality that representations with conceptual-level content (e.g., beliefs, desires, thought, etc.) arise that may be (but does not need to be) causally independent from the environmental states which an organism is currently encountering. For example, one can have a belief that “black widows are poisonous” and have access to one’s own belief “I believe that black widows are poisonous” despite the fact that there are no black widows present. What is distinctive about this notion of aboutness at the level of strong intentionality is the fact that its effects upon maintaining homeostasis occurs at slower timescales.[52] Having the belief that “black widows are poisonous” whilst living in Edinburgh is valuable to one’s adaptive behaviour even when such spiders are not native to the UK. For having such a belief could make the difference between careful and careless behaviour were one to encounter (and recognize) a black widow when visiting Los Angeles. In contrast, recall that weak intentionality is directed at environmental/sensory states that guide behaviour in the here and now. The effects of weak-intentionality-driven behaviour upon maintaining homeostasis occurs at faster timescales (e.g., the aboutness of an E. coli’s prediction that “there will be an increase in glucose concentration in THAT direction” is something that results in its immediately reducing the frequency of its tumbling behaviour and

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[52] Strictly speaking, although this is one thing that’s distinctive about strong intentionality, self-evidencing over increasingly longer timescales is a gradual property, a dimension along which the continuum runs.

bringing its actual sensory states in line with its expectations of observing nutrient rich sensory states). It is because the aboutness of mental states may operate over increasingly longer timescales, influencing both other mental states and actions, that it endows living systems with the ability to cope with the more variability in their niches.

Content at the level of strong intentionality may be generated offline and (at least in principle) may be fully insensitive to the influences of environmental stimuli, thus serving to both control and select a range of future actions (i.e., policies) in virtue of representing action outcomes over longer timescales. This naturally places those living systems that have evolutionarily developed the capacity to engender mental states in the advantageous position of using aboutness to engage in counterfactual reasoning (e.g., if I locked myself out of my flat, I would execute *such and such* a course of action to re-enter). It is important to impress that although all content across the continuum of intentionality is future-oriented, it is only at the level of strong intentionality that content may come apart from causally bringing about behaviour. And as such intentional content at this level may be relevant to a range of different behaviours across varying timescales despite an agent never actually having to initiate any one of those behaviours (see Sterelny, 2003 for a similar emphasis upon the relationship between what I am calling strong intentionality and content relevant to a range of behaviour).

I would like to suggest that since weak and strong intentionality are located at opposite ends of a continuum, there is no sharp cut-off between them. Moreover, strong intentionality may be seen as grounded in the same anticipation-driven, self-preserving processes that underwrite weak intentionality. To use a phrase coined by Godfrey-Smith (1996), that weak intentionality “shades off into” strong intentionality does not imply that the former does not play a role in underwriting the latter. On the contrary, without the kind of weak intentionality that drives adaptive behaviour at shorter timescales, it would seem that strong intentionality could not arise. Consistent with BA’s evolutionary assumption that ‘higher’ cognition has evolved from simpler cognitive capacities, strong intentionality may be seen as an evolutionary achievement. I suggest that BA should construe strong intentionality as a variable trait that was *built upon a foundation of weak intentionality* and selected for because it allowed complex organisms to respond to selective pressures across progressively longer timescales and environments with more behavioural complexity.

One may reasonably speculate that the arrival of strong intentionality and the biological hardware underpinning it on the biological scene was closely linked to the fact that meeting selective pressures placed new requirements on organisms as they began to inhabit environments with more complexity (or their niches grew in complexity) (Godfrey-Smith, 1996). One such requirement may have been being able to understand causal relationships without requiring that the agent itself be the cause. Intentional content that could be generated and monitored without entailing any behaviour at all, by allowing an agent to influence long-timescale dynamics and efficiently influence and predict other agents' behaviour made complex environments less hostile. The conditions underpinning the transition from lesser to increased environmental-organismal complexity might very well be a matter of what Sterelny (2003) describes as move from inhabiting "informationally transparent environments" (i.e., environments in which there are one-to-one mappings between sensory cues and environmental resources) to inhabiting "informationally translucent environments" (i.e., environments in which there are many-to-one or one-to-many mappings of sensory cues to resources).[53]

Strong intentionality and the conceptual representations that often accompany it, as I am envisioning them, allow organisms to exert influence upon the protracted and often informationally ambiguous environmental dynamics that are specific to

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[53] Importantly, Sterelny suggests that the increased complexity of informationally translucent environments is partly due to presence of hostile agents (i.e., prey, predators, and competitors) which pollute environmental information for a given agent via the subversion of that agent's efforts or concealment. This induces the possibility of false negatives, making the obtaining of resources expensive.

complex environments. They allow such organisms to utilize control states (i.e., conceptual-level representations) that become further and further removed from influencing and the influence of current environmental states. On the other hand, when simpler organisms are able to meet the selection pressures in their lesser complex environments, using conceptual representations that are suited to long-timescale environmental dynamics to guide behaviour in the here and now falls short of being an adaptive strategy. For too much organismic (i.e., model) complexity (relative to the level of environmental complexity that 'satisfices' for self-preservation) renders an organism's responses inefficient, slow, and often detrimental to its survival. This illustrates what is known in the Free Energy Framework literature as the model-accuracy vs model complexity trade-off (FitzGerald, Dolan & Friston, 2014). Although this may be the case, a continuum of intentionality helps to illustrate how responding to shorter timescale dynamics and less complexity nonetheless involves behaviour that is driven by weak intentionality; behaviour that is driven by future-oriented and action-oriented representations which recapitulates the normativity intrinsic to an organism's phenotype-relative internal dynamics (i.e., generative model).

We can therefore agree with Adams that conceptual representations are distinct from sensory representation while rejecting that only conceptual representations demarcate the domain of the cognitive. As one moves from weak to strong intentionality, the content and the kinds of representations change from having content that is directed at target objects/gradients causally underpinning sensorimotor behaviour to having content that can be directed at one's own mental states (e.g., a belief about one's own belief – that it is false). As one moves along the continuum from weak to strong intentionality, there is also a move from representations that are behaviour entailing and influenced (but not fully) by impinging sensory stimuli to personal to representations that are behaviour contingent and possibly stimulus insensitive (i.e., content being immune to the influenced the impinging sensory stimuli) (see chapter 5). As the continuum approaches stimulus insensitive representation, agents acquire the capacity to shift from behaviourally exploiting their environment to exploring their environment with no goal other than to reduce the complexity of their models through epistemic foraging (see Figure 3).[54]

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[54] A further manner of understanding this transition across the continuum––at least along part of the continuum—is as a passage from minimal-perception to ‘maximal’ perception, such that one moves from content that is about changes in meaningful gradient intensity to content that is about the sources of the gradients (i.e., objects). A detailed account of minimal perception will be provided in chapter 2.

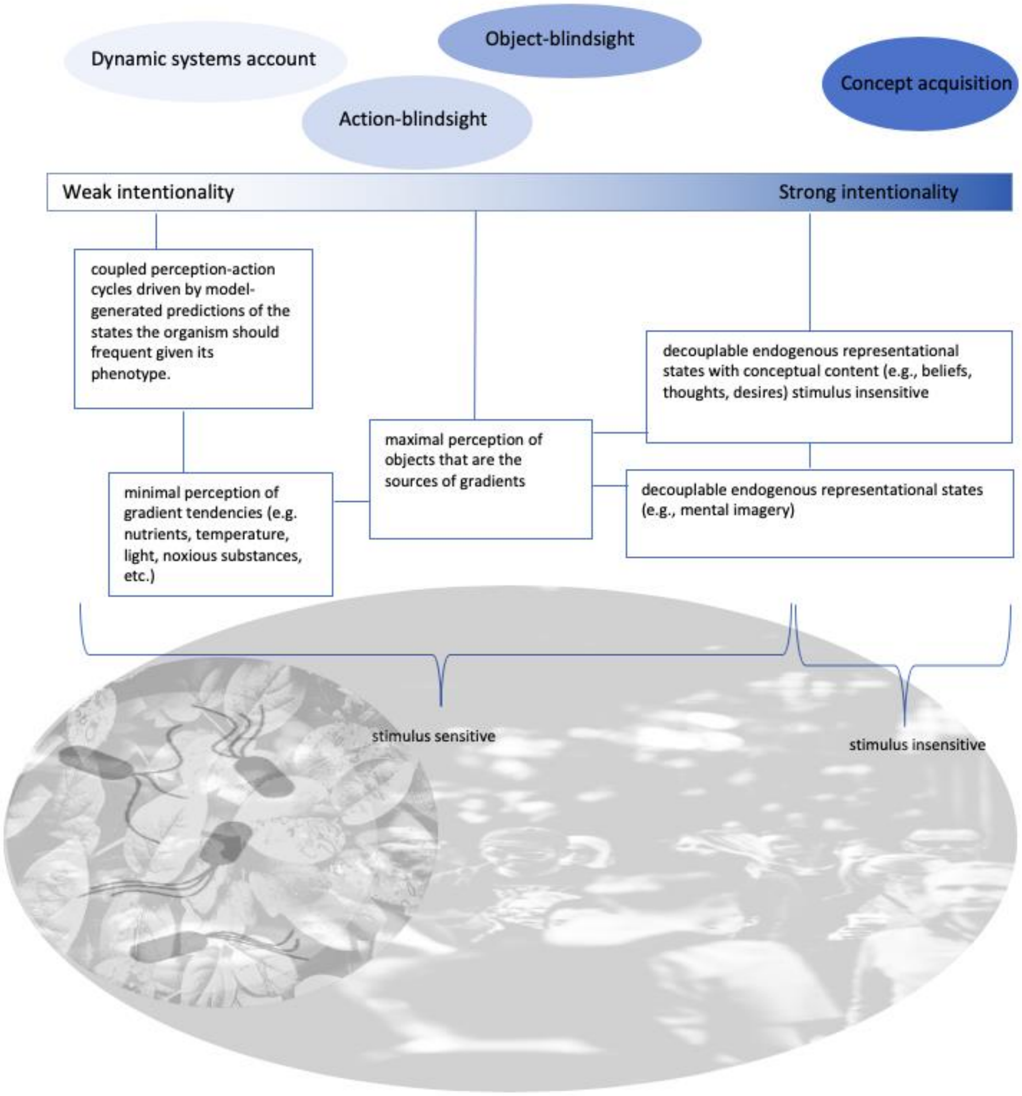

Figure 3

A continuum of intentionality: (Above) some of the various research programmes which might be seen to investigate forms of cognitive phenomena associated with a particular degree of intentionality; (below) some of the primary attributes of representational content as it is located at various places upon the continuum and capacities associated with them.

1.4.4 Overly Permissive or Not?

The initial worry which set the stage for Adams' classification methodology and its upshot, the argument from intentionality, was that BA is overly permissive. Now given what has been said regarding the intentionality continuum, is there any reason for thinking that this worry has been defanged? One may still be concerned that if the behaviour of all organisms is driven by weak intentionality and intentionality more generally is the mark of the mental, then the behaviour of all organisms is driven by cognition. If this is correct, then BA is still too liberal and thus has little explanatory currency. However, from what has been proposed above, there is no reason to think that weak intentionality is something which drives the behaviour of all living systems. If there are living systems which fail the capacity for higher-order homeostatic influence, then such systems are not driven by weak intentionality; they are mere reactors to their environment. The extent to which weak intentionality is a widespread feature of living systems is an empirical question that cannot be answered from the safety of an armchair.

Given that evolution has endowed various forms of life with different (yet related) forms of cognition, the onus is placed upon the biogenic theorist to sharpen the concepts that delineate various forms of cognition (see for example van Duijn et. al., (2007) who develop one notion of minimal cognition; di Primio, et al., (2000) for a different notion of minimal cognition; Calvo & Friston (2017) who develop the hypothesis of plant predictive processing from within the Free Energy Framework). Part of this work, if the intentionality continuum thesis is on track, will include identifying the differences in the processes and mechanisms that map on to these various forms. These evolutionary transitions in cognition may be fuzzy, but this should only be expected given that biology is itself a fuzzy matter.

1.5 Conclusion

From the perspective of BA, a complete investigation of cognition does not involve relinquishing AA full stop, but rather rejecting the notion that all forms of cognition must satisfy human-based demarcation criteria. If what I have argued in this paper is correct, weak intentionality may serve as a common feature of cognition for both BA and AA; a feature that in ensuring that both approaches are not talking past one another, allows for the possibility of a complete investigation of cognition in its various expressions and degrees of complexity. As such, both BA and AA are valid starting points for investigating the related assortment of capacities that drive adaptive behaviour at various timescales. Whether or not a scientist starts with human capacities or with the weak-intentionality-driven behaviour of simple living systems depends largely upon her/his explanatory interests. The intentionality continuum thesis offers a coherent manner of bringing these starting points together. Far from being harmful to cognitive scientific enquiry, as Adams suggests, a rich biogenic programme offers a peek inside the possible evolutionary development of the predictive brain by way of its noncentralized predecessors.

With having established the intentionality continuum thesis on behalf of BA as a plausible manner of linking biogenic and anthropogenic perspectives, let us now turn to the task of using FEF, PP, and EP to throw into relief one specific form of cognition: minimal perception.

Chapter 2

Minimal-Perception: Responding to the Challenges of Perceptual Constancy and Veridicality with Plants

Abstract

Plant predictive processing (Calvo & Friston, 2017) suggests that plants anticipatorily perceive their environment. This hypothesis runs up against a challenge which takes the form of two constraints on perception advanced by Tyler Burge (2010): the veridicality constraint and the constancy constraint. This paper argues that satisfying the veridicality constraint falls out of assuming a general account of predictive processing. To show how the constancy constraint may be fulfilled, an ecologically informed account of invariant pick-up is developed and given place within plant predictive processing. It is concluded that, pace our anthropocentric folk-psychological notions of perception, there is reason to believe plants engage in minimal-perception.

2.1 Introduction

This paper takes as its starting point the hypothesis of plant predictive processing (PPP) (Calvo & Friston, 2017), an account of plant perception based upon a free-energy principle-friendly predictive processing.[55] PPP runs up against a notable challenge which takes the form of two plausible constraints upon perception offered by Tyler Burge (2010):

(a) Perception necessarily involves the veridical or non-veridical representation of the environment.
(b) Perception is constitutively characterized as involving the representation of constancies.

A considerable problem arises for PPP if either of (a) or (b) cannot be satisfied. Namely, it would stand that plants would be an example of free-energy minimizing organisms that fail to perceive. So, unless some principled account as to how plants could veridically represent their environments and engage in constancy representation may be offered, the notion of perception used in PPP (and more generally in the Free Energy Framework) may be at best thought of as a mere heuristic; free energy/prediction error minimization in persisting biological systems does not imply the advent of anything perception-like.

In responding to (a) I shall argue the veridicality constraint may be satisfied given that predictions are systematic and integrated states with accuracy conditions. In responding to (b), which I take to be the more formidable challenge, I will look to a

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[55] PP and the FEF are independent frameworks and thus the truth of one does not hang upon the truth of the other. PPP however situates PP within the FEF in order to present a case for plant perception.

feature of ecological psychology: invariant pick-up,[56] suggesting that constancy representation may be unpacked as the behaviour enabling extraction of invariant structures in the environment; something that may be evidenced by the behaviour of plants in circumstances in which such pick-up is the best explanation for their anticipatory behaviour. Although the form of constancy representation that plants engage in is less complex than the kind that other more complex creatures might exhibit, it is nonetheless constancy representation and thus a kind of perception. This kind of constancy representation will be argued is part and parcel of simple, medium-bound invariant pick-up and marks the bounds of *minimal-perception*.

This paper shall be organized as follows: *Section 2.2* will briefly review PP and the FEF. *Section 2.3* will provide a detailed explication of PPP as hypothesized by Calvo and Friston (2017). *Section 2.4* shall introduce Burge's veridicality constraint and show how it may be satisfied by plants. *Section 2.5* will expound upon constancy constraint and then offer an ecologically-inspired account as to how plants exercise constancies in terms of the pick-up of invariant environmental structure. I will then argue that the means by which both of Burge's constraints are satisfied seems to suggest that plants exhibit a particular form of perception: *minimal-perception*. I will conclude with some brief remarks about what minimal-perception means for the scope of model organisms considered relevant to psychological investigation. Lastly, a suggestion will be made as to how the minimal-perception/perception demarcation may possibly underlie a principled distinction between non-conscious and conscious perception.

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[56] In what follows I will assume that the ecological apparatus of invariant pick-up can still be used within a perceptual theory that involves both *representation* and *inference* without rendering the latter two notions superfluous. It is not my aim to remain true in any strict sense to an ecological account of perception, but rather to bring some of the ecological mechanisms to bear upon the plant perception/cognition debate whilst attempting to respect many the motivations of ecological psychology. For a recent account of ecological cognitive architectures that remains strictly non-representational see for instance, Raja V. (2018, pp.:29-51).

2.2 Predictive Processing and Free Energy Framework

The account of perception provided by predictive processing (PP) (Clark, 2013, 2016a; Hohwy, 2013) places primary emphasis upon the hierarchical minimization of precision weighted prediction error.[57] Let us unpack this claim. Predictions, or mock sensory signals, are engendered by a hierarchically structured generative model. Generative models may be roughly thought of as a highly integrated, context sensitive, statistical 'knowledge' stores that are the result of learning at both phylogenetic and ontogenetic timescales. Predictions are generated hierarchically such that at each level 'top-down' predictions attempt to accommodate incoming 'bottom-up' sensory signals at each level below, with those predictions generated at higher levels subsuming those at lower levels. Prediction generation itself over the long term is said to 'approximate' Bayesian inference (Friston, 2009; Clark, 2013; Hohwy, 2013; Wiese & Metzinger, 2017). The signals at each hierarchical level which have been previously and successfully matched (i.e., those that have been incorporated into the generative model over time) act as empirical priors for the predictions about the current activity occurring in the respective levels below them. Any disparity between top-down predictions and bottom-up signals results in residual prediction error (PE) which propagates upwards and laterally and is met with further predictions. Prediction error minimization involves both updating predictions to match sensory signals (i.e., perceptual inference) and an organism's initiating change in its relation to its environment, thereby sculpting sensory signals to match predictions (i.e., active inference). It is in virtue of this continuous and coupled process of bringing predictions in line with the world and the world in line with predictions that the distal causes of sensory stimulation, according to PP, come to be perceived.

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[57] Precision weighting is the amplification of error signals given their estimated reliability.

PP may be itself located within the broader Free Energy Framework (FEF). FEF states that all biological systems that maintain their structural integrity in the face of the 2nd law of thermodynamics must minimize free-energy (Friston & Stephan, 2007; Friston 2009, 2013). Free-energy is an information theoretic measure which sets the upper bound on surprise (i.e., it is always greater than or equal to surprise). Systems that minimize free-energy must thereby minimize an upper bound on surprise. Surprise, or self-information, is the amount of discrepancy between the expected attractor states of a system (understood as the range of sensory states which when occupied result in homeostasis) and the actual states within which that a system finds itself. Thus, in avoiding surprise an organism is able to persist by remaining in the viable range of bodily states which are optimal for the functioning of its metabolic processing. Given that free-energy is prediction error under Gaussian assumptions (Friston, 2009),[58] the relation between FEF and prediction error minimization is evident: a free-energy minimizing biological system is one which engages in perceptual and active inference in order to maintain its homeostasis and structural integrity despite the tendency of thermodynamic entropy in the universe to increase over time.

Taking this into consideration, one primary feature of FEF becomes salient, viz. anticipatory behaviour (via active and perceptual inference) is the mechanism by which any organism maintains its homeostasis (Friston, 2009, 2013; Calvo, Baluška, & Sims, 2016) and thereby perceives the world subject to its influence. Thus, Free-energy minimization over time in any biological system implies *some kind of perception*.[59] This claim is both striking and significant given that it, if correct, not only does it extend the scope of those organisms considered to be

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[58] This is just to say that mathematically free-energy and prediction error can be both described in terms of probability distributions that map the difference between expected states and actual states.

[59] This is not the claim that anything that minimizes prediction error is a perceiver but rather that any persisting *individual organism* that minimizes PE is a perceiver. Thus, entire species, although minimizing prediction error over time via natural selection, do not qualify as perceivers.

perceivers far beyond that of the received view in cognitive psychology (i.e., the view that perception is limited to those organisms in possession of central nervous systems), but it also challenges our inherently anthropocentric folk psychological views of perception. One possible consequence of taking an FEF friendly PP seriously is plant perception.

2.3 Plant Perception

Although the notion of plant perception still remains a controversial one despite receiving some attention (Calvo, 2016), a reasonable case for it has been recently put forward by Calvo & Friston (2017), hereafter C&F. Their hypothesis, referred to as plant predictive processing (PPP), proposes that plants possess an *anticipatory* architecture that allows them to continuously look ahead, predicting the states of their environment "so as to adapt to local conditions via phenotypic plasticity" (Calvo & Friston, 2017, p. 4). This plasticity is expressed, for instance, in the process of nutation (i.e., the directed or non-directed movement of plant organs associated with non-reversible, non-turgor related growth). The argument for PPP is grounded upon the basic assumption that the FEF is true. The conclusion that plants (seem to) engage in prediction error minimization and hence perceive the environmental causes of their sensory perturbations may be drawn from assuming the FEF and the added uncontentious premise that plants are self-organizing biological systems that persist. As C&F write:

> "But to *survive* [emphasis added] plants rely upon the veridical perception of their surroundings. To do so, predicting their own states of sensory stimulation, and not merely reacting to them proves crucial" (Calvo & Friston, 2017, p. 2).

Crucially, by predicting the impinging flows of sensory stimulation via continuous error minimization, a plant comes to perceive the causes of those very sensory flows. Plant perception is thus hypothesized as being an active anticipatory engagement involving endogenously generated top-down predictions in anticipation of incoming bottom-up signals rather than mere passive signal detection of bottom-up stimuli. Let us now go over the details of the PPP hypothesis.

2.3.1 How Plants Perceive

To make sense of prediction error minimization in plants, one must be able to firstly make sense of the notion of generative models 'in' plants. In illustrating how a plant might instantiate a generative model, C&F remind us that it is only necessary to start from the assumption that it is in virtue of minimizing prediction error a plant (or any other self-organizing system) maximizes model evidence (i.e., self-evidence), thus enabling it to stay within its viable bounds. In this respect a persisting plant—or likewise any other biological agent—is (physiologically and functionally) a generative model of its econiche (Calvo & Friston, 2017).

Perceptual inference in plants, like in animals, is postulated to come about by the generation of predictions about incoming sensory states which are likely to arise given the sensory states that have already been encountered and the gradual reduction of error through the updating of predictions. Importantly, PPP emphasizes that prediction error minimization is an anticipatory process: it is not the mere reduction of current error through the updating of predictions but a simultaneous process of gathering evidence for those environmental states most likely to be encountered in the future and behaving accordingly so as to pursue "trajectories that have the least free energy" (Calvo & Friston, 2017). These latter processes are a description of *active inference*. In this context plant behaviour may be cast as a purposeful altering of morphology (i.e., nutation of plant organs such as roots, shoots, hypocotyls, flowers, etc.). Crucially, active inference includes exploratory behaviour (i.e., epistemic foraging) that is carried out for the sake of obtaining information relevant to the best error reducing future actions. C&F express this point when writing:

> “Plants are continually swaying their organs towards energy gradients, attempting to realize the most likely (least surprising) implications of sensory stimulation for subsequent engagement with the world” (Calvo & Friston, 2017, p. 3).

Bringing the notions of generative models and active/perceptual inference together, it is in virtue of the explorative sampling of their milieu that plants actively harness evidence for the generative models which they embody by confirming the predictions that such models generate. Harnessing such self-evidence and thus avoiding surprise over time by appropriately behaving entails homeostatic maintenance.

Moreover, C&F present evidence that plants also satisfy various functional and physiological conditions required for PP. With respect to satisfying functional conditions, plants are able to *contextually integrate various sensory signals/parameters* so as to assess environmental conditions (Calvo & Keijzer, 2011). Research by Gagliano et al. (2016) has shown that plants exhibit the *capacity to learn*, something required for adaptive generative model updating. By repeatedly exposing the garden pea, *Pisum Sativum*, to a fan generated air flow followed by a reward (i.e., exposure to light), such plants tend to grow towards the air movement even in the absence of light. This result provides striking evidence suggesting that plants have the capacity to engage in associative learning. It has also been shown that plants possess the *ability to flexibly* and *anticipatorily behave*. For example, Novoplansky (2016) has demonstrated that plant nutation occurs in response to anticipated future competition of resources. In addition, studies by Karpinski & Szechynska-Hebda (2010) suggest that photosynthetic adjustment in plants occurs in response to anticipated changes in light conditions.

With respect to satisfying PP's physiological conditions, C&F suggest that the activity of the vascular system and plasmodesmata could allow for the kinds of *functionally asymmetric message passing* and *hierarchical structure* fundamental to the PP perceptual story. The vascular system, the conducting tissues consisting of the phloem and xylem that carry amongst other things water, sap and nutrients, possibly implements top-down and bottom-up bidirectional signalling. Plasmodesmata, channels that extend across cell walls of adjacent cells, are reasonable candidates for lateral signal passing. The action and variation potentials found in plants which underwrite signalling, like those of animals, have an electrophysiological profile of polarization, depolarization and hyperpolarization (Calvo & Friston, 2017; Calvo, Sahi & Trewavas, 2017). Referencing earlier work (Calvo, Baluška, & Sims, 2016) C&F postulate that "the capacity to anticipate may be implemented for instance in temporal patterns of synchronous oscillatory firing of specific populations of plant cells" (2017, p. 6). Such oscillatory firings have been found to peak in the transition zone (TZ), an area in the root apex (Baluška & Mancuso, 2013).

2.3.3 What Plants Perceive

Assuming that plants do engage in the kind of prediction driven dynamics that PPP hypothesizes, then it follows that they perceive the *distal causes* of their proximal sensory stimulation. It is possible to interpret C&F as understanding such distal causes as the altering global structure of available resources. Such an interpretation is made explicit when C&F remark:

> "[…] rather than responding to mere *absolute* resource availabilities, plants are able to perceive and integrate information regarding *dynamic changes in resource levels* and utilize it to anticipate growth conditions in ways that maximize their long-term performance. Roots don't simply just grow. They constantly assess the (future) acquisition of minerals and water" (Calvo and Friston, 2017, p. 4, my emphasis).

On this interpretation plant behaviour is directed *at changes* in resource intensities in the fluctuating heterogenous mediums with which they interact. Perception is not of instances of chemo, geo, thermo, mechano, magneto or photo-stimuli per se, but of the *changing gradients* of the relevant resources (i.e., stimuli decreases, increases or uniform distributions). In the case of nutrients, it is these stimulus gradients that are followed until the gradient's peak is reached (A. Trewavas, personal communication, April 24, 2018).

To sum up, if PPP is correct, plants, like animals, engage in *a kind of perception* of their distal environment. Although plant perception is quite unlike the perception of folk psychology, it is nonetheless perception. To be clear, one may at this point forcibly take the position that 'perception' as used by FEF (and thus PPP) is a mere heuristic. 'Perception' is a device that is put in place for the folk to come to grips with the mathematically complex computational underpinnings of the FEF and is not in any sense truly perception-like. In order to establish the claim that plants exhibit a kind of perception and hence that perception as used by PPP is not a mere heuristic, something other than our anthropocentric reactions must be used as a metric in reaching a warranted conclusion. For this purpose, let us now turn to Burge's (2010) two constraints on perception.

2.4 Burge's Veridicality Constraint

A first constraint on perception that Burge proposes is that it involves the possibility of representational success or failure.[60] Burge grounds this claim in reasoning that whilst perception is the product of *objectification*, mere proximal sensory registration is not. Let's unpack this. Burge postulates that the relation which holds in sensory registration between proximal stimulus and encoded state is one of statistical correlation. Transduced states, in virtue of a creature's evolutionary history, have come to carry information about certain proximal states. This information carrying, although necessary, is not sufficient for perception because it occurs independently from certain processes which demarcate mere proximal idiosyncratic simulation from stimulation that has a high probability of being caused by distal environmental features. It is via the use of such processes or what Burge calls *formation operations* that objectification takes place.

Formation operations are "law-like regularities in the perceptual systems that reflect or mirror law-like regularities in the distal environment" (Burge, 2010, p. 346). Objectification is the "formation of a state with a representational content that is *as of* a subject matter beyond idiosyncratic, proximal, or subjective features of the individual" (Burge, 2010, p. 397). According to Burge, since the notion of content only makes sense in terms of its having veridicality conditions, and having such content is the result of objectification, the product of which is perception, issuing states with content that is veridical (or non-veridical) is a necessary constraint upon perception. Burge expresses this when he conjectures:

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[60] Success according to Burge, is equated with veridical representation or having a high degree of correspondence to distal environmental states. Failure is equated with illusory states which result from the underdetermination of causes by proximal stimuli.

> “Perception is a sensory capacity for objectified representation. Representation is a condition constitutively associated with veridicality conditions—for example, perceptual accuracy” (2010, p. 317).

Crucially, perceptual capacities serve a distinct function, viz. to veridically represent distal entities via objectification processes. Burge grounds this constraint in the assumption that perceptual psychology’s use of representations (veridical and non-veridical) to account for the problem of perception and their role in perceptual psychological explanation has been a fruitful endeavour.[61] This is contrasted to the function of biological explanations which aim to explain various processes in terms of their functional contribution to adaptive behaviour. And thus, for Burge, it is a category mistake to understand non-veridicality in terms of failing to function in a way that promotes survival. Veridicality and non-veridicality are strictly limited to the domain of psychological explanation. Sensory registration, on the other hand, is a process which does not admit of accurate or inaccurate beyond talk of biological functions. Veridicality applied to sensory registration is explanatorily superfluous.

Assuming this constraint is reasonable, can any sense be made of going from the claim that plants register proximal stimuli to the claim that plants engage in veridical perception of their distal environment? A case may be made for answering this question affirmatively. Remembering that according to PP it is the distal environmental causes of proximal states that are perceived, any theorist who accepts that an FEF-nested PP offers a correct account of perception in animals also has reason to accept that plants accurately (or inaccurately) perceive their distal environments. The reason for this being that animals, according to PP, perceive distal causes in virtue of prediction driven hierarchical dynamics. Such dynamics importantly allow for prediction error minimization and depend upon

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[61] This problem, often called the problem of underdetermination, asks how perception of particulars and properties could arise from underdetermining proximal stimuli.

having the right kind of physiological structure that supports the integration of multiple sources of sensory information and learning (i.e., updating generative models) and the ability to flexibly and anticipatorily behave. As we have seen, there is reason to believe that plants have such a structure and sufficient evidence that they engage in sensory integration, associative learning and anticipatory behaviour. Thus, there is also reason to believe that plants—like animals—have the structure and capacity to engage in processes which allow them to perceive the distal features of their environment.

Furthermore, and crucially, the principles underlying prediction error minimization (e.g., hierarchical approximation of Bayesian inference, etc.) suggest that the error signal which results from the mismatch of sensory signals and prediction signals could act as the demarcation of perceptual objectification in Burge's sense. For it is implicit in the notion of hierarchical prediction that there is systematic signal integration of sensory states and priors which allows for the statistical formation of the most probable sensory signals to come. Mere sensory registration occurs below the threshold of residual error signal generation. What occurs above this threshold is the formation of states with veridical (or non-veridical) content. This is supported conceptually in that the notion of X's being a *prediction* (or mock signal) only makes sense in terms of X's having the capability of being accurate or inaccurate.

The Burgean, in response, is likely to argue that PPP nonetheless fails to respect the distinction between psychological function and biological function. This is illustrated clearly by the fact that the FEF underwriting PPP aims to provide a computational level framework that explains how biological systems resist entropic equilibrium. This response, however, falls short of threatening the claim that plants have states which are veridical or non-veridical. If the generation of prediction error marks off proximally registered sensory states from states that represent distal environmental features, then the fact that PPP pays heed to biological self-maintenance as an aim in the formation of prediction signals and updating of the generative model only shows that *on Burge's own account* the line that he draws between psychological and biological functions is theoretically questionable. Furthermore, if PP/FEF offers consistent explanations for a plethora of psychological phenomena, as has been illustrated by the vast success in computational modelling and experimental research (Friston, 2009, 2010, 2013, 2018), then a lack of explanatory success is not what stands in the way of biologically sensitive accounts from providing fruitful psychological explanations.[62] To conclude: if plants maintain themselves via prediction driven dynamics, and predictions are states with accuracy conditions,[63] then as such there is no reason to suppose that plants cannot satisfy Burge's veridicality constraint. Let's now turn to what I consider the more formidable challenge: perceptual constancies in plants.

2.5 Burge's Constancy Constraint

Burge holds that objectification is a fundamental aspect of perception. It is the presentation of concrete objects, events, relations or attributes beyond the proximal sensory registrations of the organism; something which is perceived as distinct from the perceiver and the perceiver's perspective. As a 'rough' necessary and sufficient condition on perceptual objectification, Burge introduces the notion of constancy perception. Constancies are "capacities to systematically represent a particular or an attribute as the same despite significant variations in registration of proximal stimulation" (Burge, 2010, p. 408). The idea being that sensitivity to

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[62] Burge's assumption that perceptual psychology is essentially concerned with accuracy/inaccuracy may be questioned for the reason that it seems to selectively ignore programmes such as ecological psychology (Gibson, 1966, 1979; Turvey et al., 1981; Warren, 2005; Bruineberg et al., 2018) and enactivism (Varela et al., 1993; Chemero, 2009; Bruineberg et. al., 2016).

[63] Strictly speaking, Free-energy minimization itself needn't be unpacked in terms of psychological states with accuracy conditions but may be described purely in terms of state dynamics (Friston & Stephan, 2007).

constancies allows a perceiver to (re)identify a particular as *the same particular* despite changes in that perceiver's perspectival relations to it.[64] Constancies, as such, are "paradigmatic marks of objectification" (Burge, 2010, p. 413). It is my aim in what follows to provide the reader with an account as to how constancy representation might occur in plants.

2.5.1 Constancies as Gibsonian Invariants

As a preliminary to laying out an account of constancy perception in plants, it is necessary to introduce the notion of environmental information which emerged out of J.J. Gibson's (1966, 1979) programme of ecological psychology. According to Gibson, perception is a direct process (i.e., not involving awareness of mediational entities) by which an animal is able to extract environmental information from a perceptual medium (e.g., light, air, water, etc.) that its perceptual system has evolved a sensitivity to. Environmental information, or what Gibson called *invariants*, is the unchanging structure (e.g., ratios and proportions) in the medium disclosed under perspectival transformation. It is in virtue of an organism's moving about in the environment (or something's moving about in relation to the organism) that its perceptual system begins to 'pick-up' invariants amongst the many other changing stimuli registered. Importantly, invariants lawfully *specify* those environmental features that they structurally correspond to. It is by picking-up invariants that an organism perceives the environmental layout specified by those invariants. Moreover, it is not merely the layout that is perceived but rather the affordances (i.e., the species-relative opportunities for action offered by the layout)

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[64] Some common examples of perceptual constancies explored in the perceptual psychology literature are those associated size, shape, distance, motion and colour.

that are perceived. Figure 4 illustrates the role that invariant pick-up plays in the ecological account of perception.

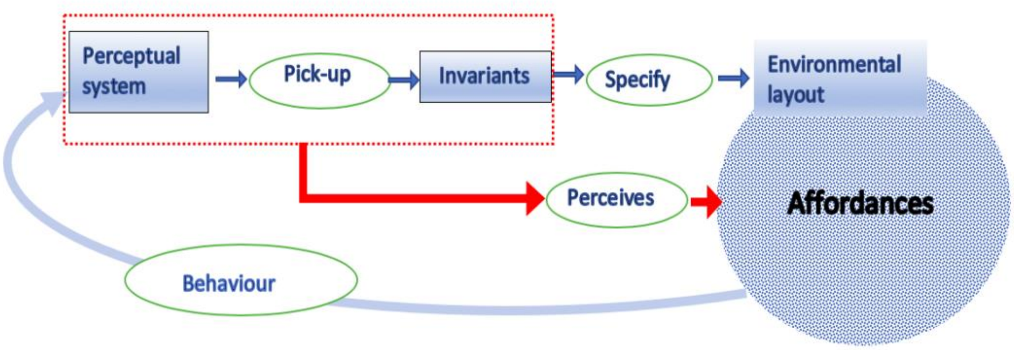

Figure 4

Affordance perception beyond the medium: guided by behaviour, the perceptual system picks-up invariants which specify the environmental layout beyond the perceptual medium. In virtue of invariant pick-up, perception of the environmental layout and the affordances it offers is achieved. This perception in turn guides behaviour and controls the manner in which the perceptual system picks-up further invariants.

In more than one place in Gibson's *Ecological Approach to Vison*, he claims that invariants are gradients or "variables between two limits" (1979, p. 116). One of the limits being the perceiver's current position, (i.e., here) and the other being the limit of the perceivable environment (i.e., there). Invariant pick-up goes beyond mere stimulus registration in that it is possible that an organism's sensory receptors may be triggered by a particular stimulus and yet if this stimulus is homogenous in its distribution across sensory receptors and time, thus failing to be differentially structured, then it also fails to activate the perceptual system. The availability or the unavailability of invariants in the medium thus marks “a clear distinction between stimulus information and stimulation” (Gibson, 1979, p. 64).

To make this notion of invariant pick-up more concrete, let us briefly turn to one invariant that has received a fair amount of attention from ecological psychologists and those sympathetic to ecological constructs: *tau*. (See Lee & Reddish, 1981: Chemero, 2009: Calvo, 2016). Tau specifies the time-to-closure of a gap between two measurable states. It is mathematically equal to the ratio of the current gap magnitude between the state that an animal is currently in and the goal state it ‘desires’ to be in and the current rate of closure (Delafield-Butt, Pepping, McCaig, & Lee, 2012). The astonishing diving practices of the gannet provide an illustration of tau in action (Lee & Reddish, 1981). These fish-eating seabirds capture their prey by diving from heights of over 90 feet at speeds sometimes reaching 100 kilometres per hour, retracting their wings only at the last moment prior to striking the water’s surface. Failing to do so at such high speeds would prove fatal. How do gannets know the precise time to retract their wings? Lee & Reddish (1981) have proposed that these birds have perceptual systems that are sensitive to tau. By picking up tau and thereby perceiving the time-to-closure, gannets are able to retract their wings at just the right moment before contact with the water’s surface.

Crucial to understanding the place of invariants such as tau in perception is grasping the notion of ‘pick-up’. Despite Gibson’s somewhat enigmatic use of this notion, I would like to suggest that one plausible interpretation of ‘pick-up’ is *the behaviour enabling extraction of the available structure in the medium by the perceptual system*. Extraction describes the process by which a perceptual system comes to calibrate itself to the structure in the world by modifying its electrophysiological profile. This modification is determined by phylogenetically and ontogenetically learned, contextually sensitive biases and available stimulus information.[65] Importantly this process enables behavioural response, which in turn controls further harvesting of stimulus information. If this construal is correct, then it entails that without enabling behavioural response—implying a minimal level of informational integration on the part of the perceptual system—or without at least some differential information in the medium, pick-up cannot occur.

With this interpretation of invariant pick-up to hand, I would like to propose an account of constancy representation that puts it to work. My proposal begins by noting that, according to Burge, being able to represent perceptual constancies is just being able to represent concrete objects as the same particulars despite changes in perspective via the use of formation operations. Similarly, invariant pick-up, the extracting by the perceptual system of structures in the medium that remain constant over perspectival transformation, is a process which enables the representation of environmental features as the same particulars.[66] Thus, both constancy representation as understood by Burge and invariant pick-up seem to be two different descriptions of how environmental particulars are perceived as the same particulars. The primary distinction between these two accounts being that the former makes use of internal computational operations, whilst the latter uses pick-up of environmental information to account for perception of the same particulars. Taking this into consideration, I would like to argue that if constancy perception can sufficiently come about in virtue of invariant structure pick-up, and there is reason to believe that plants exploit such invariant pick-up, then there is also reason to accept the claim that plants represent constancies. Assuming that the first premise of the antecedent is empirically tractable,[67] I will now turn to

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[65] Biases here need not be understood as stored states but rather as tendencies to electrochemically respond in ways that anticipate familiar structure in the world. For various accounts of biases in PP see Hohwy (2013) and Orlandi (2016).

[66] Gibson held that constancy perception *is* an act of invariant pick-up. That this is the case is clearly evident when Gibson postulates "The continuous pick-up theory of perception can assume that the apprehension of persistence [of places, objects, and substances] is a simple act of invariance detection" (1979, p. 247).

[67] The field of natural scene statistics (NSS), which has gained a fair amount of empirical support, may be seen as giving the notion of invariant pick-up of environmental information a statistical

support the second premise which will allow us to draw the conclusion that plants satisfy Burge's constancy constraint.

2.5.2 Invariant Pick-up by Plants

In support of the claim that plants pick-up invariants, I shall firstly show that the conditions under which invariant pick-up may occur are fulfilled by plants and their milieu. The first of these conditions requires that plants have the kind of morphological structure to instantiate the kind of extraction which pick-up describes. Again, extraction involves systematic biasing of internal states which reflect regularities in the environment. That this condition may be satisfied seems to fall out of the fact that plants have been shown to engage in sensory integration, associative learning and flexible anticipatory behaviour. Possessing such capacities would seemingly demand the kind of structure supporting both biasing and the ability to integrate various kinds of stimuli systematically for contextually 'informed' behaviour.

The second condition requires an available perceptual medium that the organism is sensitive to. For the purposes of this paper, I will concentrate upon one kind of medium, which in principle may serve as a model for other medium kinds. One of the many stimuli which plants are said to register are chemical stimuli. Much of this registration occurs at root apices (Blauška & Mancuso, 2013). Moreover, it is thought that various cell types located at the root cap act as distinct types of sensory receptors (Trewavas, 2016). The most reasonable choice for a perceptual

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gloss. See Orlandi (2016) for an ecological analysis of NSS. Also see Warren (2005) for additional support for constancy perception via invariant pick-up.

medium in this case is the compound mixture of water and inorganic chemical components which plant receptors are sensitive to. This mixture is conveniently referred to in plant biology as the *soil medium*. Importantly, plants, in order to absorb nutrients across their epidermal root layers, require such a mixture of inorganic nutrient and water. One such nutrient, one that is required for the production of amino acids and protein synthesis, is nitrate (NO^-_3) (Roycewicz et al., 2018; Forde et al., 2009). Nitrate, given the conditions under which it is produced—often by the decomposition of organic substances by microorganisms—may be found at varying concentrations in the soil medium. Like light, which according to Gibson is the visual medium, soil is the chemical medium for plants.

In order for information pick-up to occur, however, there must not only be an available perceptual medium which the organism is sensitive to, but that medium must be structured. It is this invariant structure which is picked-up by the organism over transformation. I would like to suggest that the structure is the gradient pattern of chemical intensities as distributed in the soil medium. This suggestion itself should not be surprising to the ecological psychologist, given that Gibson himself advocated the notion of chemical invariants, which is made explicit when he writes: “there are also surely invariants in the flow of acoustic, mechanical, and perhaps chemical stimulation, and they may prove to be closely related to the optical” (1979, p. 311). Importantly, what may be described as invariant is not the intensity level at any one moment as proximally encountered but the slope of the gradient as a function of intensity and spatial location over time. This invariant may be recognized as the constant rate of change or closure (i.e., the denominator) of the tau ratio. This objective pattern may be confirmed as the same pattern (i.e., having the same increasing or decreasing slope) under transformation.

The last condition that shall be considered is that of having the capacity to induce transformation (i.e., perspectival change generated by movement) in the medium. How may such transformation occur given the fact that plants are sessile organisms? To respond to this challenge, I would like to remind the reader that firstly plants, although sessile, exhibit root nutation behaviour. This means that over time when a root cap is exposed to a level of nitrate—or any other of the chemicals it is sensitive to—in the soil medium, as a result of growing in a direction towards (or away) from the concentration, it may initiate appropriate transformations for stimulus information harvesting.

Secondly, a plant's roots are a distributed system which together could be said to provide multiple 'perspectives' on a particular nitrate concentration *simultaneously*. In this sense, transformation is built-in to the organization of the root system as distributed in the medium. Here distinct root caps may register information which when integrated (i.e., compared with other kinds of stimulus information and conditioned on prior analogous 'experiences') is used to guide behaviour.[68] The shoot system being the most probable "arbiter of the mess of signals arising from the roots" (A. Trewavas, personal communication, April 24, 2018). Invariants picked-up in the context of this type of distributed organization would be the mutually confirming nitrate gradient pattern from various spatial locations.[69] Analogous to this, one might imagine the difference between touching an engraving of a circle on a surface with many fingers as opposed to one. Using one finger, the circular structure may be revealed only by moving one's finger along the engraving. However, such movement is unnecessary if multiple fingers are used. For although each finger comes in contact with a distinct part of the circle when many fingers are used, proximal tactile stimulus at each finger provides mutual information about the global circular structure relative to organization of the fingers.[70] Each of the two aforementioned methods of transformation respectively

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[68] Such integration, because it arises at the level of prediction and prediction error minimization, is distinct from the averaging techniques occurring during sensory registration.

[69] This might suggest that plants like animals possess a body model.

[70] A suggestive passage involving just this kind of multiple perspectives, built-in transformation that could give rise to constancy representation is offered by Burge himself when he writes of the touch system: "The touch system is capable of representing a given texture […] as the same even though the texture is rubbed against different parts of the body. Different parts of the body have substantially different sensitivities. So, the registration of proximal stimulation in the different

correspond to what I will call temporal intensity differentiation and spatial intensity differentiation.[71] A mixture of temporal intensity and spatial intensity differentiation may occur due to changes undergone by the stimuli intensity and distribution in the medium itself, say, due to excessive heat or flooding. In such cases roots may remain still while gradients around them alter.

Thus far I have provided support for the claim that plants and their environments satisfy the conditions for invariant pick-up to be possible. Satisfying these conditions, however, falls short of providing a reason to believe that plants *do engage* in invariant pick-up rather than, say, merely registering proximal stimuli available at the sensory periphery. To support the claim that plants do engage in pick-up I will now show that this process of extraction explains some accepted feature of plant behaviour that mere proximal stimuli registration fails to provide. Consider again the account of invariant pick-up suggested. It follows that plant pick-up can be characterized as *the behaviour enabling extraction of the available structure in the perceptual medium*. One way of going about adjudicating this claim is by scrutinizing the empirical predictions which would follow from its being true. One such prediction is that if plants engage in invariant pick-up, then root nutation should reflect—in the direction of growth—global stimulus structure picked-up on. As it so happens to be there is an abundance of empirical evidence that suggests just this. For example, the encountering of nitrate gradients results in growth along increasing concentration gradients and cessation when intensity peaks are reached (McNickle et al., 2009). Additionally, root territoriality, according to Calvo Garson and Keijzer “clearly illustrates the exploitation of the geometric structure itself, which in turn backs up the idea that the behaviour of plants is guided globally rather than locally” (2011, p. 164).

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rubbings are quite different. The perception is nonetheless as of the same texture. This capacity is texture constancy” (Burge, 2010, p. 414).

[71] I will assume that these differentiation methods are distinct from what Burge calls beckoning and homing techniques.

Why think, however, that these behaviours are due to invariant pick-up? Is there reason to believe that, rather than behaviours, these responses are mere reflexes coming about as the result of sensory registration? One answer might be that if a plant's behaviour were directed by mere proximal stimulus registration rather than distal structure, it might be expected that when encountering a particular chemical present in the medium a plant's behaviour would be a reaction governed by a kind of conditional rule such as: <If chemical X with strength S is encountered at L, then continue growing at L>. Were plant behaviour merely a series of reactions governed by stimulus registration and such rules, then it would be reasonable to expect that a plant would continue to grow beyond the gradient peak and then cease. To the contrary, we know that when a plant encounters a gradient peak its growth ceases (McNickle et al., 2009). That this is the case buttresses an alternative explanation: *plant behaviour is anticipatory* (Karpinski & Szechynska-Hebda, 2010; Trewavas, 2016; Novoplansky, 2016; Calvo & Friston, 2017).

It must be remembered that a plant's root nutation occurs within a heterogenous and fluctuating medium replete with both benefits and costs. In order to secure the highest biological value relative to the current state of the plant, behaviour that is guided by the anticipated globally weighted structure in the medium would seem to be more efficient in procuring a larger number of (biologically relevant) rewards over the long run while avoiding unnecessary energetic costs (i.e., avoiding surprise) than behaviour that is a mere reaction to proximal stimuli. An explanation of behaviour of this kind in terms of invariant pick-up seems to deliver just the right kind of anticipatory engagement with distal structure that matters for living organisms, the efficiency of which might be a matter of life or death. This response suggests that an explanation of gradient following when seen in the context of serving the integrity of a biological system seems to require more than mere reflex responses if the latter is not sufficient for efficient anticipatory behaviour.

Taking all of this into consideration, along with the assumption that invariant pick-up is a form of constancy exercise, brings us to the conclusion that there is reason to believe that plants represent constancies. At this point, one may raise the question as to *how the notion of invariant pick-up developed is consistently related to PP*? For without being able to make such a connection explicit and illustrating how invariant pick-up is consistent with the tenants of PP, the account of plant perception in question, PPP, fails to gain any substantial traction from the argument presented above. Responding to this question will take up the last part of this section.

2.5.3 Minimal-perception

I will now illustrate how pick-up of environmental structure may be consistently given place within PP by showing that invariant pick-up may be seen as underwritten by formation operations and formation operations are intrinsic to the prediction driven dynamics of PP. Invariant pick-up, as developed by Gibson, traditionally stands in contrast to the account of constancy representation by use of formation operations. This contrast may be explicated as the difference between viewing perception as an activity of detecting rich and abundant information in the environment as opposed to seeing it as a process of reconstructing accurate representations of environmental states from ambiguous sensory stimuli.[72] These differences in view as to the starting point of perceptual analysis are not however irreconcilable.

To see this one must only note that conceding to the claim that environmental information (i.e., structured invariants) is abundant and rich does not imply that the perceptual system is not plagued by environmental noise. We have already seen that Gibson distinguishes mere sensory stimulation from sensory information. This

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[72] Burge (2010), as far as I understand, avoids making the claim that perceivers are aware of these internal representations rather than being aware of the environment. As such, to claim that perception involves the use of formation operations to construct such representations does not suggest that perception of the world is somehow indirect.

suggests that although invariants may be ubiquitous, there is still noise that the perceptual system must deal with. One might go so far as to think that it is because there is such an abundance of environmental information available, that some of it may act as noise given the particular behavioural aims of the perceiver and the specific kinds of information that is useful in guiding that behaviour efficiently. One way, and a very efficient way at that, of disambiguating noise from useful information is to move around. Another way is to 'use' formation operations.[73] That there is no *a priori* reason why these two strategies cannot be used together flexibly and in varying degrees to suit dynamic environmental conditions suggests that such a dual strategy is possible. Possessing the property of adaptive flexibility in light of the challenges of a deeply dynamic environment suggests that it is also an efficient strategy. Thus, the motivations for a theory of invariant pick-up and for the use of formation operations may be consistently brought together in a cogent explanation of how invariants are marked-off from noise.

I would now like to go a step further and argue that invariant pick-up involves formation operations. Let me start by emphasizing that Burge is committed to formation operations as being necessary for constancy representation. More important to point out, however, is that such a commitment does not imply anything about invariant pick-up, namely that formation operations are not part of how invariant pick-up comes about. With this in mind, one may reason that if invariant pick-up is sufficient for constancy representation, and formation operations are necessarily required for constancy representation, then invariant pick-up involves formation operations.

Just what form might this involvement take? To see this, let us return to the notion of biases. The perception of constancies via invariant pick-up as developed above leans upon the notion of perceptual system biasing which occurs as the result of

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[73] This suggests something like the coupled process of active and perceptual inference in PP/FEF.

species (i.e., evolutionary) history and individual history. These biases are *systematic* in that they involve the whole perceptual system and as a result allow invariant-guided behaviour of the organism. Returning to the question as to how formation operations might be involved in the pick-up of invariant structure. The answer, I suggest, resides in how one understands the function of formation operations. Their function need not be to reconstruct accurate representations from impoverished stimuli, but rather to *guide internal state biasing*; thereby pruning the space of probable environmental structures relevant to guiding behaviour.[74] Such biasing is a tuning of the internal states of the perceptual system to the environmental information that it anticipates as being relevant for successful behaviour.[75]

This account of invariant pick-up is compatible with Burge's conception of formation operations as generally taken to "describe law-like regularities in the perceptual system that reflect or mirror law-like regularities in the distal environment" (Burge, 2010, p. 346). What Burge seems to miss, or more specifically, what the starting point of his dichotomy between biological and psychological explanation will not allow him to consider, is that not all regularities in the environment are relevant for governing the kind of behaviour that will keep a biological system alive and thriving. So, although formation operations may be construed as perceptual regularities (i.e., biases) that reflect environmental regularities, the *larger set* of perceptual regularities that may be contextually elicited at any one time is driven not by a need for accurate representation but by

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[74] One way of construing contentful states is in terms of 'action-oriented representations' (Clark, 1997). These states, rather than being merely accurate or inaccurate descriptions of the environment, also play the role of controlling action. This kind of conception of representation not only pulls its weight in explanatory power, but also bridges the gap between an active inference and an ecological account of affordance perception.

[75] The exact relation between bias formation and the ecological notions of education of attention, education of intention and calibration is an interesting topic, which given the scope of this paper cannot be pursued here. For a thorough explication of these latter notions see Jacobs & Michaels (2007).

the need to extract available environmental information that is most relevant to behaving in ways that keep an organism in its limited range of viable states.

With this picture of formation operations at hand we may now locate them within the framework of PP. When formation operations are seen as (at least partly) constitutive of invariant pick-up, they may be construed as biasing operations that govern prediction error minimization; they steer how an organism's inner dynamics model the statically probable and organism relevant external dynamics so as to enable behaviour and further pick-up. Biases, when situated in the framework of PP, might be seen priors with the highest degree of reliability. The effect of on-going invariant pick-up involving prediction error minimization driven biases is a contextual pruning of the generative model to the anticipated, behaviourally relevant structure in the medium.

Bringing PPP into focus again, the following account begins to take shape: it is in virtue of a learnt generative model, which both a plant's phenotype and electrophysiological profile embodies, along with current sensory evidence (i.e., stimulus intensity changes that are registered at the sensory surfaces) that temporal and spatial intensity differentiation get a foothold. These forms of differentiation describe the conditions under which transformations lead to the pick-up of invariant properties in the soil medium. The invariants being picked-up via hierarchical prediction driven dynamics are stimulus intensity vectors (i.e., patterns of increase or decrease in stimulus distribution in the medium). A plant, by engaging in the coupled process of perceptual and active inference, is able to extract invariants that specify features of its distal environment (e.g., the changing availability of resources). However, this in and of itself falls short of the ability to perceive the environmental layout beyond the medium. Typically, plants are *perceivers exclusively of higher-order invariants in the medium and the affordances they offer*. These higher-order invariants cause lower-order invariants and as such are lawfully specified by them. One might say that plants are blind to causes external to the medium but are acute apprehenders of opportunities for action in the medium (see Figure 5).

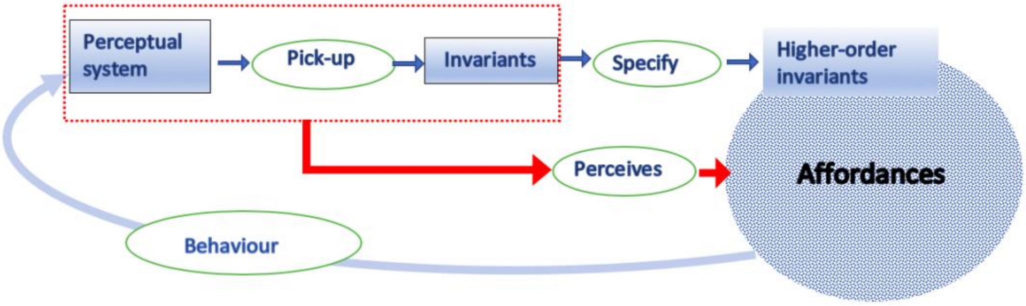

Figure 5

Affordance perception in the medium: Rather than specifying the environmental layout beyond the medium, invariants that are picked-up by plant perceptual systems specify higher-order invariants in the medium. These higher-order invariants and the affordances they offer are the objects of perception which guide further behaviour.

For a root system, affordance-offering higher-order invariants are global resource structures within the fluctuating heterogenous soil medium. These higher-order, global structures are the distal causes of the lower-order structure (i.e., local intensity gradients). To perceive the higher-order invariant structure a plant must continually predict the transforming states of the more local structure that it *anticipates* contact with. For instance, as a rodent’s carcass on the surface of the medium slowly decomposes, the soil medium becomes structured with respect to nitrogen. The locus of the intensity gradient will be nearest to the carcass. As the nitrogen becomes slowly diffuse in the medium, the pattern of its distribution and its transformation into nitrate, the non-organic substance which is valuable to a plant’s survival, is dependent not only on the features of the carcass (i.e., size, location, etc.) but upon other changing properties of the soil (e.g., the presence of soil microbe populations, water, mineral concentrations, other nearby competing roots, etc.). These latter properties, higher-order invariant structures, contribute as causes of the lower-order invariants (nitrate gradient intensities) in the medium. As such, the global structure of the medium is perceived in virtue of the local structure of the medium given that the latter is a reliable indicator of the former. By coming to anticipate the global conditions under which various valuable resources are made available, a plant can steer its behaviour in order to adapt the best global strategy for minimizing long-term prediction error.

The notion that plants perceive affordances is also nothing new to ecological psychology. Turvey et at., (1981) were early to suggest that the seedlings of the arboreal vine *Monstera Gigantea* perceives trees as climb-upable things. More recently, the perception of climb-ability by bean plants has been explored in relation to the detection of tau (See Calvo, Raja & Lee, 2017). Although affordances may be subject to accurate perception or misperception (Gibson, 1979), the fact that their existence depends upon species-specific phenotypic traits illustrates that the subjectivity of the organism cannot be cleanly pulled apart from the objectivity of its world. As such, “an affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy” (Gibson, 1979, p. 129). To the degree that constancies are marks of objectivity (Burge, 2010), if understood in terms of both lower-order and higher-order invariants, then constancies are marks of organism-environment mutuality. To conclude: invariant pick-up may be consistently given place within the framework of PP given that invariant pick-up involves formation operations and those operations are nothing other than context elicited, highly reliable priors in PP. Therefore, the use of invariant pick-up in fulfilling the constancy constraint is a tenable move on behalf of PPP.

Invariant pick-up as understood by the ecological orthodoxy is a process, the nature of which is to specify particulars in the environment external to the medium. This law-like specification relation comes about in virtue of the environmental features being causes of the structured medium.[76] However, on the account developed here, plants perceive higher-order invariant structures *in the medium*. One worry that might come about is that limiting perception to the structure in the medium places a veil between the environment and the (plant) perceiver. This worry is largely unfounded. For the medium and its properties are concrete particulars in the extra-organismic environment. Thus, in picking-up on the global structure in the soil medium, a plant is perceiving its environment. I would like to now suggest that one thing which might largely distinguish plant perception from the kind of perception which cognitive psychology has traditionally been at ends to study is that while plants *typically* perceive only those properties of their perceptual medium, animals, in contrast, may in addition to this perceive the causes of those properties external to the perceptual medium.[77] This type of medium-bound higher-order invariant pick-up is what I call *minimal-perception*.

I would like to draw the reader's attention to the qualification 'typically' as used to describe the different perceptual capacities that plants and animals may possess. This qualification is important for the reason that the perceptual capacities of some plants may not be exclusively minimal. Take, for example, the Venus fly trap (*Dionaea muscipula*). This insect eating plant captures its prey in virtue of keeping track of the number of times that the tiny hairs resting upon the inner surface its folding, trap-like leaves are triggered (Böhm et al., 2016). A certain strength of mechano-stimulation when applied to the hairs elicit action potentials and if there are more than two of them within 30 seconds of one another, the leaves close, capturing what could be possible prey. However, it is only as a result of continued subsequent triggering—no less than five action potentials in total—that the leaves remain closed and the process of digestion via enzyme secretion is initiated (Böhm et al., 2016). In this case, the pattern of mechano-stimuli over time specifies the

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[76] See Bruineberg et al., (2018) for an account of specification that is reliable and yet not law-like.

[77] That animals also perceive properties of the perceptual medium has been advanced by some perceptual analyses of olfaction. Millar (2018) holds that what is smelled is not the object emitting the odour but the chemical odorant itself.

biologically relevant cause of that kind of pattern. Five action potentials or more specify moving, ensnarement-resisting, nutrient providing prey, and this is just what the Venus fly trap's behaviour anticipates and is geared towards. In the context of minimal-perception, what this example seems to illustrate is this: although it is not a defining feature of plants, *exclusively engaging in minimal-perception may nonetheless be seen as a typical feature of plants*. Similarly, possessing non-minimal perceptual capacities may be said to be a typical feature of animals rather than being a defining feature. Sponges (*Porifera*), for instance, may be minimal perceivers tout court, picking-up on invariant properties of water flow gradients. (See Ludeman et al., 2014 for an account of cilia as sensory organs in sponges).[78]

Given that it is medium-bound, the spatial and temporal scales which minimal-perception tracks although reaching out distally, are less protracted and spatially nested than those which are tracked via non-minimal-perception. In other words, minimal-perception does not exhibit "temporal thickness" (Bronfman et al., 2016; Friston, 2018). That minimal-perception need not reach beyond invariants in the medium to track their causes external to the medium might be given explanation when considering what Clark (2008) has called "the 007 principle". This principle of cognitive economy states that we should expect a cognizer to only expend as much cognitive energy as is necessary to get the job done. In other words, overly complex solutions are to be avoided where more frugal ones are available that provide the same results. Considering this, if all that exclusively minimal-perceivers, like some plants, must behaviourally adapt to—in order to persist—are the higher-order invariants in the medium and doing so is avoiding surprise, then the 007 principle suggests that there is no need for minimal-perceivers to also pick-up on the causes external to the medium. Perception of higher-order invariants in

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[78] I am indebted to an anonymous reviewer for pointing out that the capacities of minimal-perception and non-minimal-perception may not be used in any straightforward manner to distinguish plants from animals.

the medium often gets the job done for simpler organisms where the level of complexity of what is minimally-perceived and acted upon comes to match (i.e., reflect) the level of complexity of the processes by which the organism's viable states are maintained in the face of the second law of thermodynamics.[79]

2.6 Conclusion

In this paper I have argued that PPP does not buckle under the weight placed upon it by Burge's two constraints on perception.[80] Emerging out of the account of constancy representation explicated here is a new picture of the kind of perception which plants (and other organisms without nervous systems) may possibly engage in. Rather than perceiving the temporally-thick distal causes of proximal sensory perturbations, plants perceive the temporally-shallow global structure in the perceptual medium; structure that is nonetheless distal enough to allow for constancy representation and hence a form of objectification. If something like minimal-perception is correct, then it may be concluded that the notion of perception used in PPP (and more generally in the FEF) is not a mere heuristic but rather a description of various perceptual abilities which might range from minimal to 'maximal'. Minimal-perception urges us to adopt a more unified view of perception and action, giving weight to the continuity of mind and life. This being the case warrants serious reconsideration of the scope of model organisms considered relevant to the psychological investigation. This is methodologically

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[79] This kind of "complexity matching" illustrates how the environmental complexity thesis (ECT) may be leveraged across a wide problem space that involves different degrees of heterogeneity. This space invites cognitive strategies that are sensitive to the degree of heterogeneity that must be dealt with.

[80] What my argument has not shown is that plant predictive processing stands up to other conditions placed upon perception. In fact, it might be the case that what I have succeeded in showing is that Burge's constraints are too weak.

important insofar as by observing the processes under which minimal-perceivers come to adaptively respond to the dynamics of their environments, it may be possible to extract and refine common cognitive principles which span the gamut of self-maintaining organisms (Calvo et al., 2011).

Two questions naturally arise given these considerations. Firstly, *how ‘low’ does minimal-perception go?* It could very well be that simple organisms such as prokaryotes may engage in the same kind of predictive dynamics that allows them to perceive and anticipatorily behave with respect to the invariant structures in their perceptual medium. This is an open and interesting empirical question for future research. Secondly, *at what point does minimal-perception become full-blown perception?* The distinction between minimal-perception and perception might not only demarcate shallow vs deep pick-up of spatio-temporally nested causes, but importantly, this distinction, I conjecture, may mark out a transition between non-conscious and conscious perception.[81] The arrival of conscious perception may be bound up with the emergence of a pronounced sensitivity to increasingly protracted and complex causal dynamics, granting those organisms that embody deep generative models the ability to reason counterfactually. Drawing this latter conclusion is, however, overtly premature. This being said, the need for further research—both theoretically and empirically—as to the mechanisms underlying minimal-perception and how such mechanisms might be implemented in plants and other classes of nervous-system-less, free-energy minimizing organisms is certainly warranted if there is a possibility of drawing conclusions about the transition between non-conscious and conscious perception.

Lastly, further research into minimal-perception might be of particular significance for the ecologically inclined psychologist when attempting to understand how perception of affordances (i.e., opportunities for action) arises from the pick-up of

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[81] This falls in line with Friston (2018), who distinguishes conscious agents from non-conscious adaptively responding organisms in terms of the formers’ capacity for temporally-thick inference making.

invariants. It is clear that minimal-perception in plants is a research programme with much to offer. It is also clear that engaging fully with such a programme requires the overturning of a deeply rooted anthropocentric view on what it is to perceive the world. On that note, plant predictive processing might provide us with a principled place to begin.

Thus far we have seen that ecologically informed and FEF embedded PP can provide the apparatus for thinking about the notion of minimal perception. In the next chapter I will use FEF and its Markov blanket formalism to consider how another surprising form of cognition could arise from the integrated activities of multispecies cooperative associations. Thinking about what it takes to be a symbiotic biological cognizer throws into relief at least one possible manner in which life has been enriched so as to rise to the status of mind.

Chapter 3

How to count biological minds: symbiosis, the Free-energy Principle, and reciprocal multiscale integration

Abstract

The notion of a physiological individual has been developed and applied in the philosophy of biology to understand symbiosis, an understanding of which is key to theorising about the major transition in evolution from multi-organismality to multi- cellularity. The paper begins by asking what such symbiotic individuals can help to reveal about a possible transition in the evolution of cognition. Such a transition marks the movement from cooperating individual biological cognizers to a functionally integrated cognizing unit. Somewhere along the way, did such cognizing units simultaneously have cognizers as parts? Expanding upon the multiscale integration view of the Free Energy Framework, this paper develops an account of reciprocal integration, demonstrating how some coupled biological cognizing systems, when certain constraints are met, can result in a cognizing unit that is in ways greater than the sum of its cognizing parts. Symbiosis between V. Fischeri bacteria and the bobtail squid is used to provide an illustration of this account. A novel manner of conceptualizing biological cognizers as gradient is then suggested. Lastly it is argued that the reason why the notion of ontologically nested cognizers may be unintuitive stems from the fact that our folk-psychology

notion of what a cognizer is has been deeply influenced by our folk-biological manner of understanding biological individuals as units of reproduction.

3.1 Introduction

Symbioses[82] are cooperative heterospecific associations in which each symbiont partner mutually benefits from (e.g., gaining nourishment, shelter, etc.) the presence of the other partner(s). These associations have presented an interesting problem case for the notion of *biological individuality*. What it is to be a biological individual refers to what it is that makes a living system a well delineated whole. Symbiosis raises the ontological question of whether beyond classifying each symbiont as a biological individual, there is a non-arbitrary manner of classifying the symbiotic assemblage itself as a well delineated biological unit. And if so, how can this non-arbitrary manner be spelled out? Answering this question is particularly important for at least two reasons; the first being that symbiosis is ubiquitous in nature; getting clear on the conditions under which a symbiotic association qualifies as a countable biological individual allows biological explanations to parse the world up in ways that ontologically cohere with the kinds of entities that populate the world. The second reason is that conceptualizing symbiotic associations as well delineated biological units plays a significant role in coming to understanding (and offer explanations of) the move from multi-organismality to multicellularity, an example of what has been called a major transition in evolution (Maynard-Smith & Szathmary, 1995). Under the assumption that multicellular organisms evolved from multi-organismal ensembles and that

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[82] Throughout this paper, I will use the term symbiosis to refer specifically to mutualistic associations and not commensalism or parasitism.

some of these ensembles were likely symbiotic associations, understanding this major transition in evolution requires a way to conceptualize biological individuals that is not restricted to units of reproduction or what are otherwise known as "Darwinian individuals" (see Godfrey-Smith, 2013).

One way that philosophers have recently addressed this question is by conceptually developing and applying the notion of a *physiological individual*. A biological individual of this kind is a highly integrated functional unit, the heterogeneous parts of which cohere together through regulatory processes (e.g., metabolic, 67mmune-tolerance, etc.) so as to maintain the system's integrity and resist environmental forces of decay (Pradeu, 2011). Applying the notion of a physiological individual to symbioses suggests that at least some symbiotic ensembles qualify as biological individuals in their own right (Queller & Strassman, 2009; Pradeu, 2011; Godfrey-Smith, 2013; Bouchard, 2018). What qualifies some of these ensembles as physiological individuals is the high degree to which the symbionts are functionally integrated with one another. A fascinating and somewhat counterintuitive result of parsing biological world up in this manner is a kind of nesting of biological individuals in biological individuals; not only are the symbionts understood to be physiological individuals but also the symbiotic association comprised of those symbionts qualifies as a physiological individual.

This paper examines a related interesting question for any biologically informed cognitive science that takes two ideas seriously. The first idea is that cognitive processes are an enrichment of the organizational principles and properties definitive of living processes or what is called "the strong life-mind continuity thesis" (Godfrey-Smith, 1996). The continuity thesis suggests that mind, because it is an enrichment of life, might be exhibited in biological processes that prefigure those which cognitive science typically studies. It opens up the possibility that simple organisms (e.g., some bacteria and plants) may engage in cognitive processes that are not different in kind but different in degree to those processes that are paradigmatic of human cognition. The second idea is that some symbiotic associations actually do qualify as physiological individuals. Putting these ideas together the following question arises: if mind is an enriched version of life and some symbiotic associations indeed qualify as physiological individuals, is there any reason to think that some of these living associations might themselves be enriched enough so as to qualify as bio-cognizers?[83] This is not merely a question regarding a possible application of the extended mind thesis (i.e., the idea that cognitive processes can loop outside of a cognizing agent to envelop the use of external artefacts as scaffolding) (Clark & Chalmers, 1998). Rather, this is a question about the kinds of physiological individuals that we can reasonably ascribe the term "cognizer" to. It is a question about how to count biological minds. The significance of this question lies in the fact that its answer may be used to shed light upon a possible *major transition in cognition*. Perhaps there are many such transitions: the move from reflex behaviour to sensorimotor coordination; the move from non-sentience to sentience; the move from individual intentionality to group intentionality. However the question which this paper will investigate concerns the transition away from short-term, slightly integrated cooperative interaction between simple cognizing physiological individuals towards the long-term, highly integrated cooperative interaction of the component parts of a complex cognizing symbiotic whole; each of the parts becoming more specialized in the function it plays in driving the behaviour of the whole integrated system.

Given the major transition in evolution from multi-organismality to multicellularity, and assuming that at least some of those component organisms that eventually constituted multicellular organisms were cognizers, symbiosis provides an opportunity to think about how an ensemble of minded physiological individuals became a single physiological individual with one mind. Like the nested-ness of physiological individuals, the possibility of a symbiotic mind suggests that a symbiotic cognizing unit may be comprised of nested symbiont cognizers. And

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[83] This paper's scope will be strictly limited to investigating *biological* cognizers or what I will often call "bio-cognizers".

much like the nested-ness of physiological individuals runs counter to our folk-biological conception of biological individuality, this idea that cognizers can have other cognizers as constituent parts seems to go against the grain of our folk-psychological conception of what cognizers are. One aim of this paper is to argue that the possibility of symbiotic minds provides a reason to believe that our folk-psychological conception of “cognizer” may be in need of serious revamping in this regard.

To support the notion of symbiotic minds and the notion of nested biological cognizers that falls out of it, this paper will develop and deploy the notion of *reciprocal multiscale integration* from within the Free Energy Framework. Reciprocal multiscale integration describes the case where each of two (or more) cognizing systems uses the other to provide evidence for its own model of the world (and itself acting in that world). It is when each cognizer reciprocally contributes to the cognitive processes of the other that an emergent action capacity arises. This is a capacity to act upon the environment which outstrips the individual action capacities of each partner; the capacity of the whole being more than that possessed by the sum of its parts. It is this emergent action capacity that allows a symbiotic unit to provide evidence for its own model of the world and hence for its own continued existence. Reciprocal multiscale integration builds upon the multiscale integrationist view of the Free Energy Framework (Ramstead et al. 2019; Hesp et al., 2019). This view uses the notion of nested Markov blankets to demonstrate that cognitive systems have a plurality of ontological boundaries, each relevant to the study of cognition. Reciprocal multiscale integration, on the other hand, is a manner of accounting for the nested boundaries of *cognizers* as opposed to the integrated boundaries of the nested non-cognizing constituents of cognitive systems. Like the multiscale integration view, reciprocal multiscale integration deploys the Markov blanket formalism ontologically. As it will be discussed in section 2, the Free Energy Framework (FEF) (Friston, 2010, 2013) is a framework that sees both life and cognition as coming about in virtue of minimizing the quantity variational free energy (henceforth free energy). The reason for using FEF to investigate and argue for a symbiotic mind is not only because the quantity “free energy” provides a measure of *cognition* across spatio-temporal scales (Ramstead, et al. 2019; Friston, et al., 2015; Kirchhoff & Kiverstein, 2018a), but because FEF and its various corollaries suggest a plausible criterion for identifying biological cognizers across various spatio-temporal scales. In other words, the theoretical apparatus that falls out of FEF may be used to arrive at an account of the kind of enrichment of living processes that are required for those processes to qualify as cognitive processes ascribable to physiological individuals; thus, making good on the project of strong life-mind continuity.

As a case study in support of the notion of symbiotic minds I will look at the symbiosis of *Vibrio fischeri* bacteria and the bobtail squid. I will argue that the *Vibrio*-squid assemblage constitutes a functionally integrated cognitive whole, the Markov blanket of which constrains those of the *Vibrio* and the squid. In showing how the notion of a symbiotic mind can be supported by reciprocal multiscale integration within FEF, this paper contributes to the philosophy of cognitive science, demonstrating that our folk-psychological conception of what cognizers are requires rethinking. Moreover, if the account of symbiotic cognizers presented is tenable, by bringing into relief and accounting for at least one possible transition in cognition, this paper contributes to a more complete understanding of the evolution of cognition.

This paper shall proceed as follows: In *Section 2*, after briefly reviewing FEF and exposing its criterion for being a cognizer, adaptive active inference, I will explicate the multiscale integrationalist approach as a manner of individuating the boundaries of cognition. In *Section 3* I will look at the symbiosis of *Vibrio fischeri* bacteria and the bobtail squid before turning to some philosophical implications of this symbiosis that are significant to thinking about symbiotic minds. In *Section 4*, building on the multiscale integration view, I shall provide an account of *reciprocal multiscale integration* and argue that some symbiotic associations and their symbiont constituents may simultaneously be construed as biological cognizers when reciprocally integrated. This paper concludes when some brief remarks addressing the problem of nested-cognizers.

3.2 The Free Energy Framework – a short overview

The Free Energy Framework (FEF) (Friston, 2010, 2013, 2019a, 2019b), an ambitious unifying cognitive framework that may be applied to any biological system, starts from a particular view of life that is grounded in statistical physics. In nature, most systems self-organize to thermodynamics equilibrium. This means that all energy gradients for such systems have been consumed; something that entails death for living systems. Staying alive on the other hand requires that the states of a system behave in ways that counter the dissipative effects of random fluctuations. In other words, a biological system is one that self-organizes to a limited set of attracting states that is far from thermodynamic equilibrium (Nicolis & Prigogine, 1977; Friston, 2013). This set is referred to as a system's *nonequilibrium steady state density* (NESS) (Seifert, 2012; Friston, 2019b; Friston, Wiese & Hobson, 2020; Palacios et. al., 2020). Importantly, the NESS density, towards which an organism's dynamics flow, corresponds to its phenotype (i.e., its regular patterns of behaviour, morphology, and physiology), to find itself in its characteristic or phenotypic states provides the organism is evidence that its behaviour is countering dispersive effects of random fluctuations. Hence, for a biological system to remain alive is for it to revisit the states defined by its NESS and to remain statistically separate from the environment in which it is embedded. Statistical separation is cast in terms of a conditional independence exhibited between the system's internal states and the external states of its environment.

This brings us to the second primary feature of FEF: *the Markov blanket formalism*.[84]

The Markov blanket formalism as used in the context of FEF and biological systems describes a particular kind of statistical organization of a system relative to that which the system is not. Namely, it describes the statistical partitioning of internal states I and external states (φ) by sensory (s) and active states (a), these latter states being the states of the Markov blanket. The behaviour of the internal states may be predicted fully from knowing the states of the Markov blanket and as such the external states are rendered uninformative. Internal and external states are thus conditionally independent. This conditional independence falls out of the partitioning rule: internal states influence active states, which influence but are not influenced by external states; external states influence sensory states, which influence but are not influenced by internal states (Friston, 2010). These dependencies/independencies do however allow for like states to influence like (see Figure 6).

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[84] The notion of a Markov blanket (Pearl, 1988) was originally introduced in the context of graph theory, where it describes a set of topological properties of a Bayesian nets. Specifically, a Markov blanket is the *smallest set of nodes* in a larger set of nodes, which if given information regarding their states would allow for the prediction of the unfolding states of a target node. This set of nodes includes *parents*, *children* and *co-parents*. The conditional independence between the target node and the nodes outside its Markov blanket mean that the latter are rendered uninformative or informationally redundant by the Markov blanket. The description of this set of nodes in terms of active, and sensory states is specific to FEF and its corollary active inference.

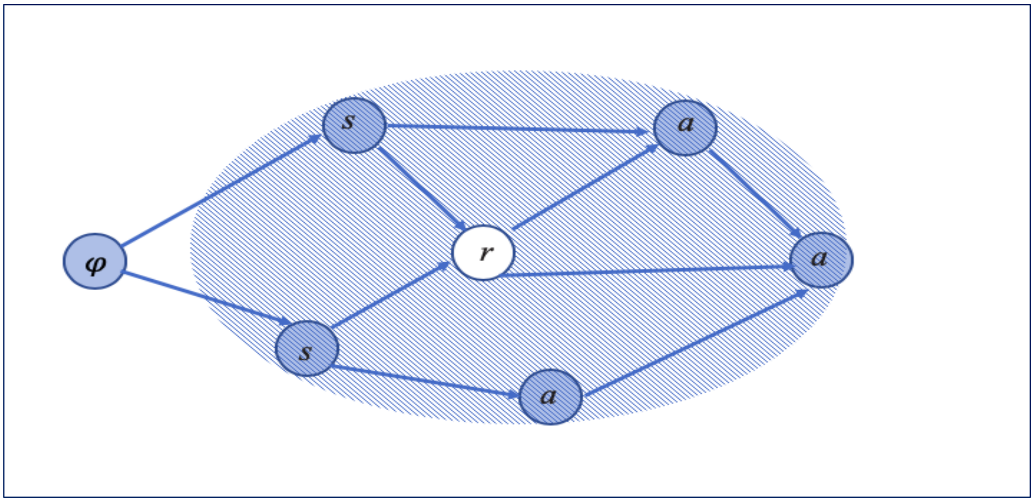

Figure 6

Markov blanket partitioning rule: sensory states (*s*) influence but cannot be influenced by internal statI(*r*). Active states (*a*) influence but cannot be influenced by external states (*φ*) This relation results in a conditional independence of internal and external states, where if one knows s and a at time, t-1, the knowledge of *φ* at time, t-1, provides no additional information about the internal state at t.

Active and sensory states create a statistical partition between internal states of the system and external states of the environment, forming “a surface or boundary that defines the thing that exists (e.g., a cell membrane) (Friston, 2019a, p. 176). Although this conditional independence implies that the internal states remain statistically distinct from external states it should not however be taken to imply that such a system is causally isolated from the environment. Biological systems are self-organizing thermodynamically open systems that operate far-from equilibrium. (Turner, 1982). The manner which biological systems resist dispersive effects of fluctuations in their external milieu, and hence remain far from thermodynamic equilibrium, is by exchanging matter and energy with their environment (Friston, 2013; Demirel, 2014). These exchanges are mediated by a system’s Markov blanket via circular causality: external states causally influence internal states by way of sensory state changes and internal states causally influence external states by way of active state changes. As such, although the system individuated by its Markov blanket is statistically independent from its environment, the formalism as used within FEF suggests that such systems remain tightly coupled to the dynamics of the environment (Friston, 2013, 2019a). This brings us to a third essential feature of FEF: the notion of a *generative model*.

A generative model is a probabilistic model that describes how the evolution of sensory states of a Markov blanket could be caused by external states; it captures prior 'beliefs'–in the form of probability distributions–about unobserved external states, and a likelihood mapping external states to the evolution of sensory states. Such models are "implicit in the dynamics of internal states" (Palacios, et al. 2020 p.2). Importantly, a system's generative model may be cast in terms of its NESS. To see how this is the case requires understanding the notion of *dual information geometry* of self-organizing systems (Friston, 2019b; Parr et al., 2019; Friston, Wiese, & Hobson, 2020)

FEF describes the long-term dynamics of a self-organizing system in one of two mathematically equivalent ways that depend upon such a system's having a Markov blanket and, hence, its existing at nonequilibrium steady state. The evolution of a system's states (i.e., its flow) may be described dually in terms of (1) its *phase space dynamics* or (2) its *statistical manifold dynamics*. With respect to its phase space description, every instantaneous state of the system is represented by a point in phase space (i.e., a space of all possible states that a system could occupy), every variable in the system corresponds to a dimension of the phase space, and the evolution of states over time corresponds to particular trajectory in phase space. Under this description, the probabilistic flow of a system's states over time is known as its *intrinsic* information geometry (Friston, Wiese, & Hobson, 2020). A system's *extrinsic* information geometry describes the probabilistic flow of a system's states over a statistical manifold, upon which each manifold coordinate corresponds to the sufficient statistics (i.e., the mean and the variance of a Gaussian) defining a probability density (i.e., a probabilistic 'belief' about external states). Adjacent points on a statistical manifold represent densities that are alike, and the distance between points (i.e., “information length”) along a manifold path scores distances between probability densities encoded as points on that path respectively (Friston, 2019b; Friston, Wiese, & Hobson, 2020). In short, while intrinsic information geometry is a description of the probabilistic evolution of states system itself, extrinsic geometry is a description of ‘belief’ distributions over external states that internal states of a Markov-blanketed system encode.

FEF suggest that as long as a system possess a Markov blanket, rendering the system (i.e., its internal and active states) conditionally independent from its embedding environment, the flow in phase space towards the NESS density can be expressed as a probabilistic flow towards ‘belief’ distributions about external states. As a result, FEF allows for the remarkable observation that the NESS density towards which any self-organizing system tends to flow is that system’s generative model. Given the presence of a system’s Markov blanket, its intrinsic and extrinsic geometries coincide, meaning that a biological system’s phenotype dually corresponds to its NESS density and to its generative model.[85] How does a system’s generative model contribute to the continued maintenance of its Markov blanket? This brings us to the fourth primary feature of FEF: *active inference*.

Remaining alive (i.e., statically separate from the environment) is a continuous feat that is accomplished despite the tendency for all systems to approach thermodynamic equilibrium. As such, living systems appear to resist the second law of thermodynamics. FEF proposes that living systems are able to do this in virtue of avoiding sensory states which are deleterious and actively bringing about those sensory states which allow them to maintain their structural and functional integrity. These latter kinds of phenotypically determined sensory states describe those which an organism expects itself to be in—given its generative model—and,

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[85] I would like to thank an anonymous reviewer for calling my attention to the importance of the phenotype’s dual aspect.

as such, act as evidence for its existence (Kirchhoff & Kiverstein, 2019b). This is just to say that an organism must thus pursue those actions which bring about evidence for itself over the long run (this includes exploration) and avoid those situations which could possibly result in its systemic dissipation. How does an organism accomplish this?

The free-energy principle that states that for any biological system to remain alive, it must minimize a quantity known as variational free energy. Variational free energy[86] (henceforth, "free-energy") is an upper bound on the information theoretic surprise[87] (i.e., the negative log probability of sensory states) and is a function of probabilistic 'beliefs' encoded by internal states of a Markov-blanketed system. Free-energy may be thought of as the difference between the sensory states an organism expects to observe given its generative model (or equivalently, its NESS density) and those that it actually observes at its sensorium. According to FEF, free-energy can be minimized by (1) inferentially optimizing the internal states of the Markov blanket so as to accommodate sensory states (i.e., perception), and (2) inferentially optimizing active states of the blanket (i.e., action) to sample sensory states that are expected given its phenotype. It is by engaging in this coupled process of *active inference*[88] that an organism minimizes not only current free energy encountered but expected free energy (i.e., the free energy that would arise were a particular action policy selected and followed). It should be impressed that the inference of active inference does not presuppose personal level

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[86] Free energy is under some simplifying assumptions—the details of which I cannot treat in this paper—is mathematically equivalent to the quantity "prediction error" (Friston, 2010) that is typically referred to in predictive processing. In what follows I shall use both free energy and prediction error to refer to the same quantity unless noted otherwise.

[87] Surprise (i.e., negative Bayesian model evidence) is itself a computationally intractable quantity because it requires that biological systems have access to something that they generally do not have access to. Namely, it requires access to all the possible ways in which sensory states could have been caused (Friston, 2010). Since free-energy is an upper bound on surprise (i.e., free-energy is always equal to or greater than surprise) and because it is something that biological systems do have access to (i.e., it is a function of a generative model), it may be used as a proxy quantity for surprise. That is to say that by minimizing free-energy an organism can minimize surprise and maximize model evidence.

[88] It should be impressed that "inference" as it is used within FEF is understood as a subpersonal process.

inferential processes; rather, it describes the dynamics which underwrite the optimization of internal states and prediction driven sensory feedback control.

Minimizing free energy over time is the same as maximizing *Bayesian model evidence* (i.e., self-evidence) (Friston, 2013; Hohwy, 2016). This is because when an organism's generative model is well-tuned to its environment the discrepancy between the kinds of states that the organism expects to observe (i.e., states that confirm its own existence) and those that it does observe is at a minimum; its internal states may be thus understood as a model of the external states of its niche (Friston et al., 2015). It is thus by minimizing the free energy bound on surprise via active inference that biological systems "maximize the lower bound on the evidence for an implicit model of how their sensory samples were generated" (Friston, 2013, p.2). An interesting result of casting the NESS density as the generative model is that the gradient ascent of a system towards its NESS density may be described "as if" that system is minimizing variational free-energy and hence harvesting evidence for its generative model. To say that a system will behave "as if" it is performing a gradient descent on free-energy is a description that falls out of the fact that there is a dual information geometry (i.e., one can interpret a system's gradient ascent on an attracting set through phase space in terms of its flow towards a generative model on a statistical manifold). In sum, to minimize free-energy is to maximize evidence for a generative model which is just maximising evidence that the flow of the system's internal and blanket states is approaching its NESS density (i.e., flowing towards the system's attracting states that counter fluctuation effects).

3.2.1 Enriching Life with Autonomy - Adaptive Active Inference

There are two important points about FEF that are worth noting. Firstly, FEF is not only a theory of cognition but a theory of life; mind and life are both underwritten by the same fundamental principle of free energy minimization and come about via the kind of Markov blanket-preserving adaptive behaviour that is expressed by active inference. FEF as such is ideally placed as a framework within which to investigate the notion of enrichment that is central to the strong life-mind continuity thesis. Moreover, because FEF does not specify the manner in which active inference is physically implemented, this framework may be used to theorize about cognition in a range of living systems of varying complexity (see Auletta, 2013; Calvo & Friston, 2017; Kirchhoff, 2018; Sims, 2019).

This brings us to the second point of importance. FEF falls short of making the claim that all Markov blankets draw a line around cognizers. It has been suggested that what determines whether a living Markov blanketed system is cognizer is whether or not it is the kind thing which engages in “adaptive active inference” rather than “mere active inference” (Kirchhoff et al. 2018). Adaptive active inference requires that a system *autonomously* engages in active inference, maximizing sensory evidence for its own existence (Kirchhoff & Kiverstein 2019a/2019b). Autonomy may be understood as the capacity for systemic self-evidencing through “actively monitor[ing] and react[ing] to perturbations that challenge homeostatic variables” (Kirchhoff et al. 2018, p.5). Cells, tissues and organs, although they are self-organizing, free energy-minimizing systems, fail to rise to the level of bio-cognitive individuals because the manner in which they provide evidence for themselves (i.e. for their generative models) is highly dependent upon the machinery of and their interaction with other components of a global system (Kirchhoff & Kiverstein, 2019a). As such, FEF (or more specifically its corollary adaptive active inference) boldly suggests that one manner in which life may be enriched so as to rise to the status of mind is tied to the increased degree of autonomy of the living Markov blanketed system

The distinction between adaptive active inference and mere active inference offers a manner of addressing a *prima facie* worry that active inference (and FEF more generally) might be thought to face: ascribing Markov blankets to all living systems is intuitively unattractive if it brings with it the claim that all living systems engage in active inference. If something like a red blood cell actually engages in active inference, then despite the fact that inferences are understood as subpersonal descriptions of internal dynamics this result seems to make active inferential a trivial notion. This trivialization worry however may be avoided when recognizing that although every living thing is enshrouded by Markov blanket, this does not entail that every living thing engaged in the kind of adaptive active inference that is required to be a cognizer. In other words, one can understand the Markov blanket formalism as a genuine manner of individuating all living systems (it is not merely way of modelling them)[89] while distinguishing the highly autonomous manner in which bio-cognitive systems maintain and preserve themselves and the highly interdependent manner that non-cognizing living systems maintain and preserve one another. The distinction between adaptive active inference and mere active inference demonstrates that active inference if far from a trivial notion – the devil's in the detail.

To sum up: FEF (or more specifically its corollary adaptive active inference) boldly suggests that one manner in which life may be enriched so as to rise to the status of mind is tied to the increased degree of autonomy of the living Markov blanketed system. With this understanding of FEF and adaptive active inference in hand, let

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[89] That FEF holds Markov blankets to be ontologically robust may be supported by Friston when he writes that a Markov blanket "is not some statistical device by which we come to observe or model the world—it is a necessary attribute of a universe that can be carved into things (that are distinct from other things)" (Friston, 2019a, p. 176).

us now briefly look at the multiscale integration view, which lays much of the theoretical ground upon which the notion of a symbiotic mind (and nested bio-cognizers) can be developed.

3.2.2 Multiscale Integration

The multiscale integrationalist view (Ramstead, Kirchhoff, Constant, & Friston, 2019; Hesp, Ramstead, Constant, Badcock, Kirchhoff, & Friston, 2019) is a pluralist theory about cognitive boundaries; it uses the notion of nested Markov blankets to demonstrate that cognitive systems have a plurality of ontological boundaries, each relevant to the study of cognition.[90] Cognition is seen as falling out of active inference that spans across and integrates various nested Markov blankets at different spatio-temporal scales (Ramstead et al., 2019). To support this position, the multiscale integrationalist view offers a nuanced manner of spelling out just how the boundaries of cognitive systems are both nested and multiple via the process of multiscale integration. Take for example a human cognitive system which is composed of a brain; which is itself composed of cortical layers; which is composed of a collection of neurons; which are composed of individual neurons, etc. According to the multiscale integrationalist view each of the spatio-temporally nested components of this cognitive system may be ontologically picked out by deploying the Markov blanket formalism at different scales. Any one Markov blanket located at one spatio-temporal scale is simultaneously composed of other nested Markov blanket constituents at the scale below and is itself a constituent of a larger Markov blanket at the scale above it.

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[90] If the multiscale integrationalist view is correct, then cognition can be a spread-out endeavour, the kind which often involves not only the brain but the dynamic and every-changing involvement of the body along with aspects of the environment – a view that is consonant with 4E theories of cognition (Clark, 2008; Chemero, 2009; Gallagher, 2005).

The temporal dynamics between scales differ such that the smaller the scale is, the faster the dynamics are. The slower dynamics of macroscale systems *constrain* the faster dynamics of the microscale Markov blanketed systems, in effect acting as an order parameter[91] (Kirchhoff et al., 2018; Ramstead et al., 2019). The structure across scales is governed by the same conditional (in)dependencies described by the partitioning rule (Allen & Friston, 2018; Clark, 2017; Kirchhoff et al., 2018; Ramstead et al., 2019; Friston, 2019b). Since free energy is an additive quantity, the free energy which arises at the macroscale is the only free energy that there is for the ensemble and it may be quantified by summing the free energy associated with each constituent microscale Markov blanketed system. Minimizing free energy at the level of the composite system thus means minimizing free energy at the level of the constituent systems.

The process of multiscale integration may be generally understood in terms of inferences made on the part of individual Markovian partitioned microscale components (e.g. cells) of a macroscale system (e.g., a multicellular organism) that share the same generative model (see Friston, Levin, Sengupta, & Pezzulo, 2015; Kirchhoff, Parr, Palacios, Friston, & Kiverstein, 2018; Palacios, Razi, Parr, Kirchhoff, & Friston, 2020; Veissière, Constant, Ramstead, Friston, & Kirmayer, 2019). The idea of sharing a generative model may be construed in two manners given what has been said above (Section 2.0) regarding the dual information geometry of self-organizing Markov blanketed systems. When an organism's phenotype is cast in terms of its generative model, all component particles of the composite system will have the same expectations about the free-energy minimizing sensory states that should be encountered in addition to the kind of active states which are most likely to give rise to such sensory states. This means having the same set of priors ('beliefs') acquired via evolution (Palacios, et al., 2020). Integration, from the perspective of extrinsic information geometry, thus

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[91] An order parameter is a notion taken from synergetics (Haken, 1985) and used dynamics systems theory. It denotes a measure of a global system's macroscale unstable (slow) dynamics that enslaves the fast dynamics of microscale component systems and results in a globally emergent pattern.

boils down to active inference on the part of those component particles, each instantiating a generative model with the same expectations as other integrating particles. The expected kinds of interaction (sensory feedback) are constrained by the partitioning rule that governs the organization of Markov blankets at any scale (e.g., If I infer that I am in an internal state of a larger blanketed system, then I expect to be influenced by all other states with the exception of external states). To minimize its free energy, and thus provide sensory evidence for itself as a constituent of the larger system, a microscale system allows itself to be enslaved to the dynamics of that macroscale system. The whole Markov blanket ensemble is integrated in virtue of the free-energy minimizing, self-evidencing dynamics occurring across/between each spatiotemporal scale (Ramstead et al., 2019), resulting in the emergence of a composite system that possesses a new generative model at the superordinate level.

When taking the intrinsic perspective, where an organism's phenotype is cast as its NESS density, sharing a generative model may be seen as a case in which all of the subordinate level Markov blanketed particles of a superordinate system self-organize to a shared attracting set in phase space (i.e., a shared NESS density). From this perspective, the mechanics of the multiscale integration view may be understood as the idea that any living system may have multiple NESS densities, nested in successively larger spatio-temporal scales.[92] Because a Markov blanket in the case of living systems statistically maps onto a system as defined by its NESS density, multiscale integration can be understood as the idea that the coupled dynamics of multiple Markov blanket particles over time result in a new attracting state in their shared phase space. The emergence of this new attracting set is just the emergence of a system with a new NESS (i.e., a new generative model) at the superordinate level – a system that enslaves the dynamics of Markov blanketed systems at respective subordinate levels.

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[92] I am grateful to an anonymous reviewer for clarifying this point.

In providing a model of the integrated dynamics of Markov blankets across different spatio-temporal scales, the multiscale integration view offers an account of how the boundaries that compose *cognitive systems* are mutable, enveloping different component parts that contribute to the process of cognition as needed by the cognitive system. Multiscale integration of living systems that fail to possess the high degree of autonomy required of adaptive active inference (and hence fail to be cognizers) continue to engage in mere active inference at fast time scales (e.g., a mitochondrion in a cell).[93] On the other hand, multiscale integration of the nested systems that subtend the scale of a cognizing organism occurs in virtue of hierarchically "downward reaching" adaptive active inference; the behaviour of constituent nested Markov blanket systems are enslaved to the slower dynamics the autonomous cognizing organism; the subtending Markov blanketed systems become resources for the cognizing system to minimize the summated free energy across all nested blankets that compose it.[94] This integration in such a case is *unidirectional*; it is the adaptive active inference at the slower scale of the cognizing system that drives the continued integration of the nested Markov blankets at scales below it and not vice versa. Similarly, multiscale integration between cognizers and non-living artefacts (e.g., spiders and their webs) may be construed in a similar fashion. Such integration is unidirectionally driven; it is the active inference dynamics of the biological cognizer that drives integration with the non-living Markov blanked system and not vice versa.

This sets up the question which will occupy us for the remainder of this paper: what happens when the component parts of a biological system are themselves highly autonomous biological systems that engage in adaptive active inference? In other words, what happens in the case where integration involves physiological

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[93] This is not to suggest that mitochondria do not exhibit some degree of autonomy and adaptivity. However, a mitochondrion's ability to seek out energy gradients required for its continued existence has become severely limited due to the evolution of the highly dependent relationship between it and its embedding cell.

[94] Inferring from large scale to small scale thus recapitulates the kind of adaptive active inference which would drive organogenesis (or morphogenesis) (see Friston et al., 2015).

individuals that are cognizers in their own right? Whatever answering this question asks for, it most certainly requires something more than mere unidirectional integration. It requires a kind of reciprocal integration that I will argue undergirds the transition from a collection of cognizing physiological individuals to a symbiotic mind.

However, before presenting this account of reciprocal integration, it is important to understand just what kind of natural case in the world that the notion of a symbiotic mind might apply to. So, let us briefly look at one particular striking example of a symbiotic association: *V. fischeri* and bobtail squid symbiosis.

3.3 *Vibrio*-squid Symbiosis: a case study

The Hawaiian bobtail squid *Eurprymna scolopes* is a nocturnal predator of the shallow reef of the Hawaiian archipelago that rests, buried in the sands, during the day and hunts at night (McFall-Ngai, 2008). It is also prey to various marine predators. Whether or not it is preyed upon, however, is influenced by its association with bioluminescent bacteria Vibrio fischeri. The juvenile squid recruits *V. fischeri* into the epithelial-lined crypt spaces of its light organ by entraining seawater into itself with ciliated appendages (Nyholm & McFall-Ngai, 2004) Subsequently the host promotes its colonization by *V. fischeri* and only V. fischeri via the production of mucus (i.e., bacteria food), the elimination of competing bacteria through hemocyte defences of its innate immune system (McAnulty & Nyholm, 2017) and the eventual shedding of the ciliated appendages and the swelling of the crypt membranes preventing further entry into the light organ.[95]

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[95] The squid is able to control the amount of light emitted by its light organ by both contraction and expansion of the ink sac diverticula and by withholding oxygen to the Vibrio colonies which limits the amount of light the bacteria produce (McFall-Ngai, 2008).

Following gradients of chitin which they feed upon, *V. fischeri* migrate deeper into the crypts of the light organ, colonizing it, and causing (after reaching a sufficiently high density) a biochemical reaction resulting in their emission of bioluminescent light. This occurs just in time for the bobtail's nightly hunt for prey. Because of the counterillumination against the light of the moon and stars that the bioluminescence allows, the squid casts no shadow and is thus camouflaged from potential predators on the seafloor below it whilst it hunts (McFall-Ngai & Montgomery, 1990; Jones & Nishiguchi, 2004). The bacteria also benefit from the bioluminescent reaction. The process consumes oxygen and induces hypoxic conditions in the squid's crypts that bring about the exocytosis of cytoplasmic substances out of the epithelial membrane (Visik et al., 2000). It is hypothesized that bioluminescence results in the production of nutrients for *V. fischeri* (Visik et al. 2000).

The particular population of *V. fischeri* that inhabit the light organ of the squid is, however, temporary. For the bobtail, cued by the light of dawn, vents up to 95% of the bacteria every morning (Nyholm & McFall-Ngai, 2004). During the day, as the squid rests in the sand, *V. fischeri* that have not been expelled reproduce, repopulating the crypts so that by evening their density is high enough for the biochemical reaction that results in bioluminescence to occur again. After the initial colonization, this bacterial venting-repopulating cycle continues for the extent of the squid's life.

3.3.1 Philosophical Implications of *Vibrio*-squid Symbiosis

There are three philosophical implications that are exposed by this striking association that are significant to the account of symbiotic minds which follows. Firstly, the *Vibrio*-squid association is a clear example of a symbiotic physiological individual. What makes this association a symbiotic physiological individual opposed to a collection of physiological individuals? When deploying either an immunological criterion of physiological individuals (Pradeu, 2011) and/or a metabolic criterion of physiological individuals (Godfrey-Smith, 2013), given the high degree of immunological and/or metabolic functional integration between each symbiont, the *Vibrio*-squid association qualifies as a symbiotic physiological individual.[96] But does the fact that the assemblage is temporary (i.e., that some of the *Vibrio* are expelled everyday) present a challenge to the status of the *Vibrio*-squid association as a symbiotic physiological individual? Does this daily expelling suggest that a proliferation of symbiotic individuals? This brings into relief a second crucial philosophical implication: physiological individuals are matters of degree; over time the same living system can be more or less of a (symbiotic) physiological individual (Bouchard, 2018).

The last important philosophical implication may be thrown into relief when asking the critical question: what is it that produces the bioluminescence – the squid, the bacteria, or the temporary assemblage of these organisms? Fredric Bouchard (2016) argues that the bioluminescence is an emergent property of the *Vibrio*-squid assemblage. His reasoning is based upon the following facts about this case of bioluminescence. *V. fischeri* only begin to emit light when they sense a high concentration of autoinducers (i.e., a bacterial metabolic product) in the surrounding medium of the crypt (Miller & Bassler, 2001). This process of quorum sensing induces the transcription of the lux gene that results in the bacterial bioluminescent light emission (Nyholm & McFall-Ngai, 2004). Although *V. fischeri*

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[96] The immune criterion emphasizes (in)tolerance to elements with both exogenous and endogenous origins––relative to the system in question––as necessary for the kind of functional integration that a physiological individual requires. The metabolic criterion holds that a physiological individual must minimally possess its own core metabolic machinery (i.e., the machinery that results in processes of energy harvesting and energy breakdown). This machinery may also include external machinery (other environmental realizers) which regularly and closely influence those metabolic core processes. For considerations in favour of the metabolic criterion see Dupre & O'Malley (20009) and Godfrey-Smith (2013/2014). For a detailed account of the physiological criterion see Pradeu (2011/2016).

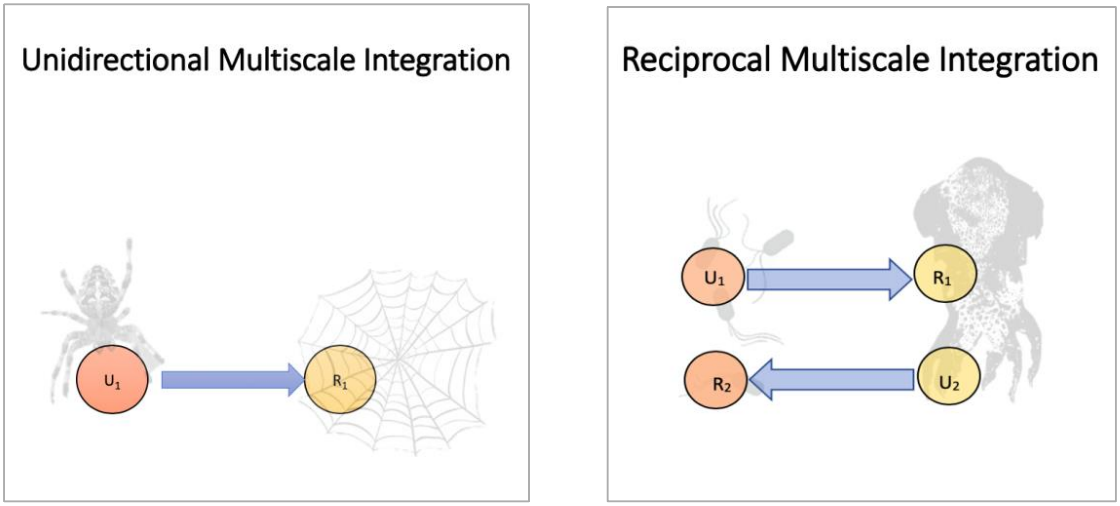
populations in the seawaters could grow to such density as to quorum sense and generate light independently of the squid, *V. fischeri* do not actually do this in the wild (Bouchard, 2016). The light organ provides just the right conditions (i.e., shelter and food) for exponential population growth (McFall-Ngai, 2008) required of quorum sensing. The bobtail, similarly, cannot generate light itself without being colonized by *V. fischeri*. If this is correct, then it is not either the squid or *V. fischeri* that glow alone but rather “what glows is a temporary assemblage of species interacting in the right way” (Bouchard, 2018, p. 190).

With this case study and these philosophical implications in mind, let us now return to the notion of reciprocal multiscale integration and to ultimately answering the question of how such a symbiotic physiological individual could be a symbiotic mind.

3.4 Unidirectional vs Reciprocal Multiscale Integration

To understand what is meant by reciprocal integration, I will now contrast it with unidirectional integration. To make this contrast apparent I will deploy the terminology of users, U_i, and resources, R_i. Users are those living systems, the internal states of which inferentially generate subpersonal predictions that allow them to use other Markov blanketed systems that are external to them. A necessary characteristic of users is that they have the capacity to engage in adaptive active inference and use Markov blanketed systems that are external to them in order to minimize long-term free energy. Where being external is relative to the Markov blankets that play an essential role to the user’s autonomous self-evidencing. Resources, on the other hand, are those external Markov blanketed systems that given their structure and behaviour provide a means for users to minimize their *long-term* free energy but are themselves not required for autonomous self-evidencing. Importantly, resources can, but need not, have the capacity to engage in adaptive active inference; they can but need not be enriched enough so as to qualify as cognizers according FEF. As such, a Markov blanketed system can be both a user and a resource.

In unidirectional multiscale integration, the internal states of U_1 generate predictions about the role that R_1 plays (e.g., sensory, internal or active state) in a superordinate level Markov blanket in which it also plays a role. In order to minimize short-term free energy that results from such predictions, U_1 acts in ways to bring about the kind of feedback that would result were it the case that both it and R_1 played those inferred roles. On the other hand, R_1 does not (and perhaps cannot) generate predictions about U_1. In contrast, reciprocal multiscale integration describes the process whereby a user, U_1, is simultaneously a resource, R_2, for a distinct user, U_2, that is itself a cognitive resource R_1 for U_1 (see Figure 7).



a.

b.

Figure 7

Unidirectional multiscale integration vs reciprocal multiscale integration: Plate a. illustrates small/fast scale to large/slow scale unidirectional integration. It is unidirectional in terms of being driven by an inferential procedure, the source of which is the user and not the resource. Here R1 is used by (represented by the arrow) a prediction generating cognizer U1 but is not itself a cognizer (i.e., although R1 has a Markov blanket, it does not engage in adaptive active inference). Plate b. illustrates reciprocal integration from small/fast scale to large/slow scale and vice versa. It occurs when users, U1 and U2, are each bio-cognizers and inferentially generate predictions about the sensory states that would be encountered were they playing different roles in the same larger Markov blanketed system. Resources, R1 and R2, are used by U2 and U1 respectively as the users engage in adaptive active inference, adapting their generative models to one another. Because U1 is R2 and U2 is R1, the integration between the users is reciprocal.

U_1 generates inferences about the role that R_2 plays in a larger Markov blanket that it also plays a role in, and U_2 does the same with respect to R_1. U_1 acts as a resource contributing to the adaptive active inference of U_2 and vice versa such that from the increasingly coupled state space of U_1 and U_2 a new shared (U_1/R_2 + U_2/R_1) NESS density emerges at the superordinate scale, enslaving both U_1 and

U_2. A new generative model emerges that not only encodes priors about the 'preferred' states of U_1 and U_2, but also encodes priors concerning the kinds of environmental conditions in which the superordinate level unit thrives in addition to the kinds of actions which bring these conditions about. The result of reciprocal integration is an extended symbiotic phenotype that authors the conditions for its own existence; by behaving in ways that optimize action, sampling the world that it expects, the integrated symbiotic unit tends to provide evidence for its own generative model.[97]

To be clear, each constituent bio-cognizer continues to engage in adaptive active inference, acting in ways that ensure it remains statistically separate from its environment. That two individuals are enslaved by a state attractor at the superordinate scale does not imply that they must renounce their autonomy to the degree of forfeiting their status as bio-cognizers. Symbiosis is an effective means of cooperatively sustaining the Markov blankets of both U_1/R_2 and U_2/R_1 separately and as a unit. Importantly, the integration of U_1/R_2 and U_2/R_1 into a unit determines a new shared Markov blanket where external states are defined by everything that is not $(U_1/R_2 + U_2/R_1)$. It is the unit which infers the states external to its blanket, differentially interacting with them in order to persist as a unit. Crucially, the manner in which $(U_1/R_2 + U_2/R_1)$ interacts with its environment cannot be reduced to the differential operations at the level U_1/R_2 and U_2/R_1. It is when they are reciprocally integrated that an *emergent action capacity* arises. This is a capacity possessed by a unit to behave in a manner which outstrips the combined individual behavioural capacities of each user. I would like to suggest that such an emergent action capacity is evidence that adaptive active inference is occurring at the level

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[97] This kind of reciprocal multiscale integration between two (or more) cognizing systems may be interestingly interpreted as a form of niche construction (Constant, Ramstead, Veissière, Campbell, & Friston, 2018; Veissière et al., 2019), whereby U_1 and U_2, co-evolve and come to play the role of exo-genetically inherited (i.e., non-genetically specified) resources for each other. Inheritance, spanning long enough timescales, becomes consolidated in the emergence of a new $(U_1/R_2 + U_2/R_1)$ NESS density at the superordinate level. I would like to thank an anonymous reviewer for bringing this insightful interpretation of reciprocal multiscale integration to my attention.

of the symbiotic physiological individual.[98] In other words, when the reciprocal integration of symbiont partners that have been evolutionarily (i.e., adaptively) coerced into following a long-term reciprocal free energy minimizing strategy do result in an emergent action capacity, this capacity is possessed by a symbiotic cognizer.

To be sure, an emergent action capacity is a property of the reciprocally integrated ($U_1/R_2 + U_2/R_1$) unit that constrains and affects the behaviour of the symbiont components U_1/R_2 and U_2/R_1. As such, how symbiotic cognizers and their action capacities arise is best characterized as a form of ontological emergence. *Ontological emergence* refers to two joint ideas: (1) some properties possessed by a composite macro-level system cannot be reduced to the structural (i.e., intrinsic) properties of its component parts and their governing micro-dynamics and (2) because of these new irreducible properties, a macro-level system has ontological status (e.g., is an entity) in its own right. (Santos, 2015). Such emergent properties at the macro-level are more than the properties of their component parts in the sense that macro-level properties have causal powers that their component parts fail to possess, enabling a macro-level system to both facilitate and constrain the very micro-level parts and dynamics that give rise to it – what is referred to as 'downward causation'. Taking into account however that both new environmental influences are specific to each hierarchical level (Gilbert & Sarkar, 2000) and that causation involved in ontological emergence is diachronic (i.e., macro-levels of a system affect micro-levels and vice versa at different sequential timesteps) (see O'Connor & Wong, 2005) emergence may be more accurately—and less mysteriously— analysed in terms of circular causation.[99,100] In fact, this circular

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[98] The *emergence* of an action capacity is distinct from the *realization* of an emergent action capacity. For example, although I may not be able to do 20 push-ups now after a long workout at the gym, I certainly still have the capacity to do so when I am rested.

[99] I am indebted to an anonymous reviewer for pushing me to clarify more about the notion of emergence being used in this paper.

[100] The contemporary notions of emergence are both various and nuanced (see for example Winning & Bechtel, 2019). Although providing a more detailed analysis of the kind of emergence involved in reciprocal multiscale integration is an interesting and valuable philosophical

causation should be expected in FEF given an understanding of the kind coupled dynamic exchanges between self-organizing open systems and their external milieu that are required for such systems to resist dispersive effects. That is, because system ($U_1/R_2 + U_2/R_1$) is causally coupled to its environment in a way that neither U_1/R_2 or U_2/R_1 are individually, ($U_1/R_2 + U_2/R_1$) has causal powers that neither U_1/R_2 or U_2/R_1 possess individually. The emergent system has action capacities that, via facilitating free-energy minimizing exchanges with its environment at the superordinate scale, constrain the behaviour of components U_1/R_2 and U_2/R_1 at subordinate scales.

Let us now concretize this somewhat abstract description of how reciprocal integration might occur at the level of the symbiotic unit and return to the case study of the *Vibrio*-bobtail squid association.[101]

3.4.1 *Vibrio*-squid Reciprocal Integration

The *Vibrio*-squid reciprocal integration might unfold as follows: the internal states of *V. fischeri*, U_1 and those of the bobtail system, U_2, come to generate the same inferences about the sensory effects that should be observed were both of the to play the role of sensory and active states in a superordinate blanketed system. For example, both U_1 and U_2 might expect sensory feedback in the form of a

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endeavour, for reasons of limited space, the more general description of ontological emergence will have to do for the purposes of this paper.

[101] The description of symbiotic cognitive integration that follows is admittedly simplified in that I shall treat the *V. fischeri* colony as a single individual. *Vibrio*-squid symbiosis, although only involving two species, involves more than two organisms (e.g., a colony of Vibrio may reach 10^[9] inside the light organ of a bobtail). Moreover, given that scale refers to spatio-temporal scale, on intuitive grounds I will stipulate that the *V. fischeri* system and the bobtail system live at different scales; the former, being smaller and faster, is nested in the latter.

reduced ambient oxygen gradient in the bobtail's light organ (i.e., an increased hypoxic state). The squid system, in order to reduce the free energy that arises as result of its inferences, acts to bring about that very pattern of protracted feedback that it expects. To do this, the squid harvests *V. fischeri*, $R_{2,}$ and only *V. fischeri* and thereafter provides conditions for their thriving from which these protracted sensory patterns may arise. When all goes well, reducing free-energy associated with the expected hypoxia allows the squid system to further influence the evolving states of its light organ; these evolving light organ states reflect the evolution of two convergent flows on a shared squid-*Vibrio* state space.

Similarly, in order to reduce the free-energy that arises from the *Vibrio* system's inferences about expected sensory states, the bacteria migrate further into deep crypts of the light organ, shed their flagella (reducing a degree of their own autonomy), and bring about a decreasing ambient oxygen gradient over time as both their density and quorum sensing increases. In this reciprocal manner, the generative models of the squid and *V. fischeri* adapt to one another, each user acting as a free-energy minimizing resource for the other. Crucially, as a result of the continued and increasing squid-Vibrio coupled activity, a new attractor emerges at a superordinate scale on their shared state space. This emergent NESS density corresponds to a new generative model that is distinct from the squid and Vibrio models that gave rise to it. Thus, by reciprocally behaving in ways to bring about the kinds of feedback that would accompany their inferred roles in a superordinate Markov blanketed system, U_1 and U_2 integrate across spatio-temporal scales, harvesting evidence for an emergent phenotype ($U_1/R_2 + U_2/R_1$) (see Figure 8). Via its influence upon the environment, this new symbiotic bio-cognitive individual both constrains and facilitates the continued behaviour of its component users and realizers.

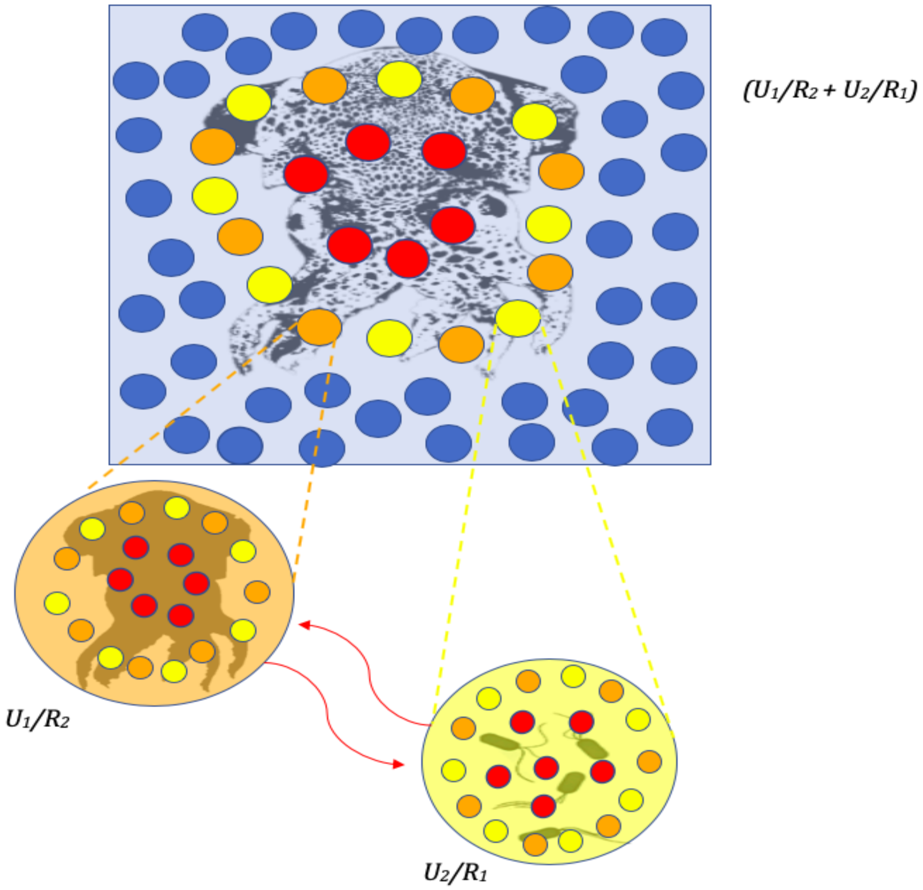

Figure 8

Reciprocal multiscale integration: the squid system, U1/R2, infers (indicated by the wavy arrows) that *V. fischeri* system, U2/R1, plays the role of sensory states (indicated by yellow nodes) and that it plays the role of active states (indicated by orange nodes) in a superordinate level Markov blanketed system (U1/R2 + U2/R1). U1/R2, becomes further coupled to the dynamics of U2/R1, actively bringing about the kind of sensory feedback that would accompany each of the subordinate level system's playing its respective inferred role in the larger blanket. Similarly, the *V. fischeri* system, U2/R1, integrates with the squid system by inferring that U1/R2 plays the role of the active states and that it plays the role of sensory states in (U1/R2 + U2/R1). U2/R1, then acts in ways to bring about the kinds of sensory feedback that would be observed were the two systems to play these inferred roles. The bacteria (user) system does this by engaging in tightly coupled behaviour with the squid(resource) system. This reciprocal integration over time results in the emergence of a new NESS density, the dynamics of which enslave those of U1/R2 and U2/R1. The resulting global emergent action capacity possessed by the symbiotic unit (U1/R2 + U2/R1) allows for a downwards causal influence upon those very systems which give rise to it. Modified from Kirchhoff et al. (2018).

The notion of environmental influence may be understood in terms of the effects of an emergent action capacity that is a property of the symbiotic bio-cognizer and not of its component parts. More precisely, as U1 and U2 become further integrated, flowing towards the new squid-Vibrio NESS density, the new system acquires a new action capacity, controlled bioluminescence, that only reaching maturation, is actualized nightly at the *peak of integration*.

This reveals a crucial point: Markov blanket integration (reciprocal and unidirectional) as located in FEF is a matter of degree. That this is the case is implied by the fact that Markov blankets can be more or less integrated over time and that integration does not happen instantaneously but is something that can increase (and decrease). The spider system that rebuilds its web after being forced to relocate to a different location is likely to integrate with its newly constructed web to a high degree only after interacting with it; this a process where internal states of the spider system calibrate to the sensory feedback that arises as external states (e.g., wind, prey, its own actions) affect the web (i.e., the resource). Integration between the bobtail and *V. fischeri* systems is a rolling diel process (i.e., a cyclical process that occurs over the course of a 24-hour period). For subsequent to the initial colonization, reciprocal integration peaks nightly with the emergence of controlled bioluminescence. This high degree of integration lasts until the symbiotic bio-cognitive individual that is evidenced by the emergent action capacity expels 95% of the *Vibrio* back into the water when cued by the first light of dawn. At this point the integration drops in degree to its lowest value of the diel cycle and the process of reciprocal integration begins anew from this lower degree until the unit, with the emergent bioluminescence, actively generates evidence for its own existence again.

Does this drop in the degree of integration that accompanies the diel cycle result in a problem of proliferating bio-cognitive individuals; short-lived individuals that spring into existence nightly and are the cause of their own dissipation at each dawn venting? I would like to argue that this problem is may be avoided when it is recognized that being a bio-cognitive individual is a matter of degree.[102] Even when the squid-*Vibrio* unit is not integrated enough to realize its capacity for controlled bioluminescence (by its glowing and using it), this does not mean that the squid-Vibrio unit is not integrated enough to *possess* the capacity. The long-lived bio-cognitive squid-Vibrio unit, through a continuous process of adaptive active inference retains this capacity and when enough free energy is minimized in the reciprocal integration process, the symbiotic unit may deploy the capacity. This suggests that when the capacity for controlled bioluminescence is not realized, the symbiotic unit is less of a bio-cognitive individual rather than losing its status full stop (see Figure 9).

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[102] This solution is consistent with the idea that a being a physiological individual is a matter of degree (Queller & Strassman, 2009; Godfrey-Smith, 2014; Bouchard, 2016); the degree of physiological individuality is proportional to the degree of functional integration. As such, then although after the venting of the *Vibrio* the squid-*Vibrio* association is less of a physiological individual it is still functionally integrated (metabolically and/or immunologically) enough to retain its status as a physiological individual.

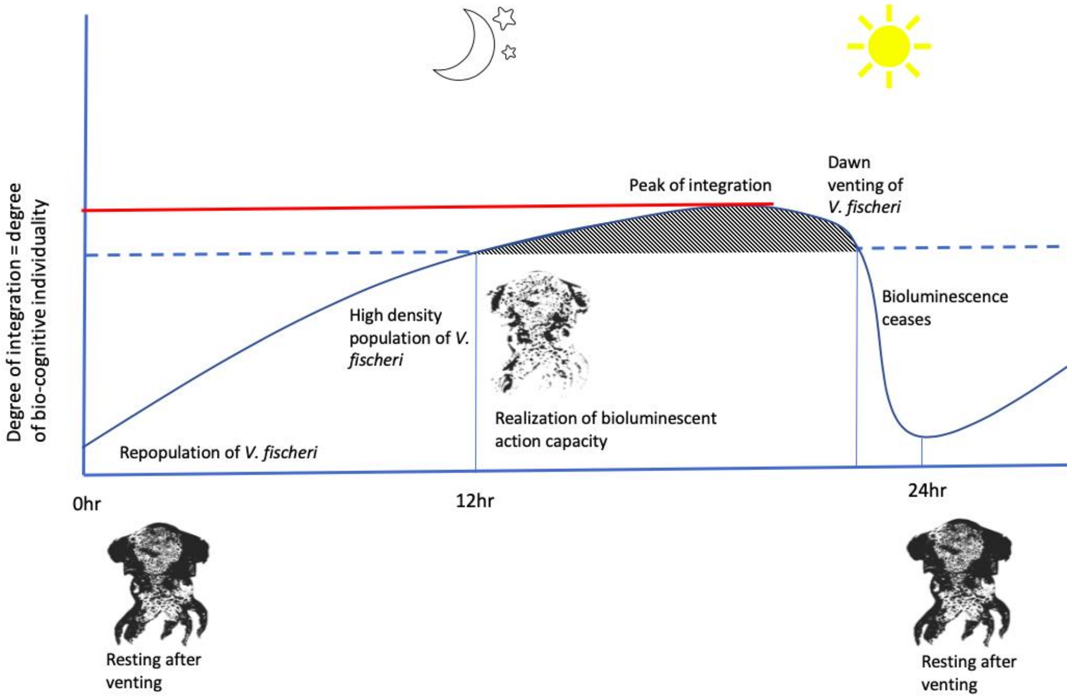

Figure 9

The diel cycle of *Vibrio*-squid integration and bio-cognitive individuality

This kind of ebb and flow of the degree of cognitive individuality is familiar in our own case. For although when sleeping we fail to use our capacities to fully engage in the kind of self-evidencing active inference, we remain bio-cognizers. What I am suggesting is that in such cases we may be bio-cognizers to a lesser degree. Moreover, the daily expelling of the *Vibrio* may be seen itself as an instance of self-evidencing of the integrated symbiotic cognizer! For if the *Vibrio* were not vented, the existence of the unit would be at risk. Venting is an active way of fostering a condition in which *Vibrio* quorum sensing will continue effectively in the future by keeping *Vibrio* in an active growth phase (Visick & McFall-Ngai, 2000). As such venting on the part of the symbiotic unit may be construed in terms of actively reducing *expected* free energy. Moreover, venting prevents the symbiotic association from becoming harmful to the squid (too high of a *Vibrio* density over a long period may result in *Vibrio* bringing about pathogenic responses).

If this picture of reciprocal integration of the squid and *Vibrio* is correct, then the *Vibrio*-squid physiological individual via reciprocal multiscale integration becomes a model of its niche; a model that is different from that of its individual symbionts. Both the existence of the symbiotic cognizer and the pattern of controlled bioluminescent masking that occurs over the course of night is evidence for the specific range of environmental conditions that have evolutionarily come to have *Vibrio*-squid-association-relative value. Expressing this point deploying the ecological notion of affordances (Gibson 1979), while the moonlit waters of the Hawaiian reef may afford safety for the integrated *Vibrio*-squid association, it fails to offer an affordance of this sort to either of the lone symbionts.

To sum up: I have argued that a symbiotic unit (e.g., *Vibrio*-squid association) that is constituted of cognizing symbionts at different scales may itself be a biological cognizing system when the symbiont partners that compose it engage in a high degree of reciprocal integration, a form of Markov blanket integration that falls out FEF. If what I have argued is correct, it is possible that in some restricted cases symbionts can maintain their status as bio-cognizers whilst simultaneously giving rise to a new NESS density that corresponds to a symbiotic cognizing individual *in its own right*.

3.5 Conclusion

I began this paper by flagging a particular concern that arises when considering the notion of a symbiotic mind. The idea that cognizers may have other cognizers as nested constituent parts is an idea that seems to run counter to our folk-psychological intuitions about what it is to be a cognizer. This concern I noted reiterates a similar worry for the physiological account of biological individuality: the hierarchically nested ontology of physiological individuals in physiological individuals flouts out folk-biological intuition that an organism cannot be a constituent of another organism.[103] This worry for the physiological account can be defanged however by pointing out that physiological individuals are distinct from Darwinian individuals (i.e., units of reproduction) and that it is the nesting of the latter that is intuitively problematic.[104] As such, folk-biological intuitions cannot be used when adjudicating the claim that physiological individuals can be nested in other physiological individuals in symbiotic associations (Godfrey-Smith, 2014). With this in mind, I would like to suggest that the worry that cognizers cannot be nested in other cognizers may stem from a similar failure on behalf of folk-psychology to distinguish physiological individuals from Darwinian individuals, overlooking the former. For if our folk-psychology implicitly models the notion of cognizers upon that of Darwinian individuals—a much more scientifically old and ingrained conception of biological individuals—then it would seem that the notion of nested cognizers would remain as unintuitive as the notion of nested Darwinian individuals. However, by reconceptualizing our folk-psychological notion of "cognizer" to include physiological individuals the notion of nested biological cognizers is no more unintuitive as that of nested physiological individuals. Moreover, given that the conception of cognizers as physiological individuals is already implicit in FEF, this framework and its corollary active inference (mere and adaptive), offer an ideal programme for bringing our folk-psychological intuitions in line with the way nature has carved its own joints over evolutionary timescales.

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[103] See S. Chauvier's (2017) "the formal indivisibility principle" for an expression of this concern which is also called "the exclusion principle" (Godfrey-Smith, 2014).

[104] Aphid-Buchnera bacteria symbiosis presents an interesting case in which the symbiotic association may indeed qualify as both a Darwinian individual and a physiological individual (for more on this see Godfrey-Smith, 2013). This suggests that our intuitions should not have the final say in biological ontologising.

In this chapter I have argued for the notion of a symbiotic cognizer, a concept that provides a way of understanding the possible evolutionary transition from multi-organismal collections of minimal cognizers to multicellular and specialized cognitive agents. In the next chapter, concentrating on context sensitive affordance perception in humans, I will introduce the notion of *historical context sensitivity*, using it to reveal a possible marker for a different form of cognition that is distinctive of organisms like us whose wellbeing is often tied up with information acquired in the past.

Chapter 4

Ecological in Spirit? Predictive Processing and the limits of direct perception

Abstract

Affordance perception is receiving lots of attention in cognitive science. Action-oriented predictive processing, one theoretical framework for making sense of this literature, views affordance perception and its context sensitivity as an indirect process involving the use of stored representational states. However, affordances as originally introduced by ecological psychology are taken to be directly perceivable. This presents a conflict between ecological psychology and predictive processing over the issue of the role of priors in affordance perception and the necessity of information processing and representation in the explanation of affordance perception. In this paper I shall introduce one form of context sensitive affordance perception, "Historical context sensitivity" as a positive argument for the appeal to computation and representation by showing how predictive processing can elegantly handle this phenomenon with its mechanism of precision weighting. It is argued that an ecological theory of direct perception, however, lacks the resources to account for historical context sensitivity. The analysis of how action-oriented predictive processing accommodates historical context sensitivity, it shall be argued, allows for a much-needed closer look at how the predictive processing

framework implicitly deploys the core ecological notion of environmental information exploitation. It is suggested that prediction error minimization can be cast as a mechanism for tuning to ecological information over time. As such, although predictive processing is not compatible with an ecological direct theory of perception, it is nonetheless in important ways ecological in spirit.

4.1 Introduction

What range of flexible and context sensitive intelligent behaviour may be accounted for without recourse to intervening information processing states? This general question has been one of longstanding interest in the philosophy of cognitive science (Turvey, Shaw, Reed & Mace, 1981; Clark, 1998; Keijzer, 2001; Noe, 2004; Wheeler, 2005; Chemero, 2009; Clark 2008; Barrett, 2015; Bruineberg, Kiverstein & Rietveld, 2016; Orlandi, 2016; Hatfield, 2019). Its importance for information processing and non-information processing accounts of cognition alike is rooted in the thought that due attention to the role of environment-body interactions reduces—if not does away with altogether—the need to posit cognitively demanding internal operations on representational states. In order to make progress on the more general question, this paper will go about investigating a more specific one; namely, can context sensitive affordance perception be fully accounted for without appealing to information processing. Since their introduction by ecological psychologist Gibson (1979/1989), *affordances* (i.e., perceivable opportunities for action that the environment offers) have populated the explanatory toolkits of numerous non-information processing accounts (Turvey, Shaw, Reed & Mace, 1981; Chemero, 2009; Van Dijk, Withagen, & Bongers, 2015; Bruineberg, Kiverstein & Rietveld, 2016; Heras-Escribano, 2019). Such ecological direct perception accounts, emphasizing the abundance of environmental information for perception, reject that inner representational states (i.e., knowledge states) play any explanatory role in accounting for affordance perception (or perception more generally). More recently, affordances have been incorporated into cognitive scientific frameworks such as *action-oriented predictive processing* (PP) (Clark, 2013/2016a). Contra to direct perception accounts, PP views affordance perception as a generative process, one involving the brain's generating representations of highly probable action outcomes conditioned on current sensory evidence (Linson, et al., 2018).

To answer the more specific question, in this paper I shall introduce what I call *historical context sensitivity* (HCS). HCS is the perceptual phenomenon in which current perception of an event/object's affordances continues to be influenced (temporarily) by a past encounter with that event/object despite there being an interruption in sensory contact with that event/object. I will argue that HCS presents at least one case where affordance perception demands recourse to the use of information processing. Notably, the analysis of how action-oriented predictive processing accommodates HCS provides an opportunity to expose and understand an important feature of PP: environmental information exploitation is implicit in PP's prediction error-minimizing dynamics. I will go on to demonstrate how prediction error minimization can be cast as a mechanism for tuning to ecological information over time. As such, although PP is not ecological in letter, it is still—at least in some important respects—ecological in spirit.

This paper is organized as follows: *Section 4.2* briefly introduces the notion of affordances and affordance perception and explicates two different accounts of affordance perception: the direct perception account offered by ecological psychology vs. the representational account proposed in cognitive science. In *Section 4.3*, after providing an overview of action-oriented PP, the specific manner in which affordance perception is construed in PP is taken up. In *Section 4.4* HCS is introduced. I argue that this form of context sensitive affordance perception presents a genuine problem for direct perception theory, but that PP can elegantly account for HCS in an ecologically indirect manner. *Section 4.5* aims for a partial reconciliation of PP and ecological psychology by making explicit how environmental information exploitation is already present in action-oriented PP. Lastly, the limits of direct perception are used to consider where and when the kind of precision weighting-based working memory becomes more relevant to context sensitive affordance perception in PP.

4.2 Affordances

Originally introduced by the ecological psychologist J.J. Gibson (1966), affordances have remained a major area of research in ecological psychology (Warren, 1984; Turvey, Shaw, Reed, & Mace, 1981; Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Turvey, 1992; Stoffregen, 2002; Michaels, 2003; Lee, 2009; Franchak, Celano, & Adolph, 2012; Rietveld & Kiverstein, 2014; Harrison, Turvey & Frank, 2016; Rader, 2018; Wagman, Stoffregen, Bai, & Schloesser, 2018; Heras-Escribano, 2019) and have inspired an ever-growing and important area of investigation in cognitive science and experimental psychology (Witt, Proffitt, & Epstein, 2004; Cisek, 2007; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Costantini, Ambrosini, Scorolli, & Borghi, 2011; Borghi, Flumini, Natraj, & Wheaton, 2012; Ambrosini, Scorolli, Borghi, & Costantini, 2012; Borghi, & Riggio, 2015; Pezzulo & Cisek, 2016). As understood by all, affordances are organism-specific *opportunities for action* that the environment offers (Gibson, 1979). They may be understood as relational properties of the environment-agent systems in the sense that affordances may only be specified in terms of the physical structure of the environment in reference to the capacities possessed by their perceivers (i.e. morphological features, physiological states and skills) (Heft, 1989; Stoffregen, 2003).[105] However, this is not to say that affordances fail to be ontologically objective; affordances exist whether or not some agent perceives them - they are "facts of the environment" (Heft, 1989, p.3). It is in this sense that affordances challenge the traditional "objective-subjective" philosophical dichotomy (Gibson, 1979 pp. 120-121).

Affordances imply that the environment, beyond being a home to objects, is endowed with value or significance that is relative to the capacities that a creature possesses. As such, they refer to both the environment and the agent (Gibson, 1979). They are an expression of one of the central assumptions of ecological psychology: *organism-environment mutuality*. This is the notion that there is a *complementarity* between organisms (i.e., their capacities and morphology) and their environment (think of the sensitivity of bee vision to ultraviolet colour and ultraviolet reflecting flowers that depend upon bees for their pollination). This is to say that neither organism nor an environment could exist in the absence of the other. As such, the opportunities for action that an environment offers a particular organism are an expression of their mutual historical and on-going influence upon one another. What has been said thus far pertaining to affordances is generally accepted by both ecological psychology and cognitive scientific views of affordances. Now let us move on to a primary area of divergence with respect to affordances between the ecological psychology tradition and cognitive science: affordance perception. In order to grasp the nature of this divergence it is necessary to first understand the details of ecological psychology's more general account of perception.

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[105] For example, although a tree branch might generally afford perching for a bird, it does not do so for humans due to differences in body scaling (among other things).

4.2.1 Direct perception

Ecological psychology views perception as a *direct* process. This may be positively defined as the claim that perception can be sufficiently accounted for in terms of the detection of ubiquitous and rich information in the environment that perceptual systems are sensitive to (Gibson, 1979).[106] *Environmental information* is construed as invariantly structured stimulus energy (e.g., arrays of light, vibration, chemicals etc.) that perceptual systems have become sensitive to over evolutionary timescales. For example, organs that are sensitive to patterns of electromagnetic radiation have been selected for in environments where electromagnetic radiation is present and where using differentiated patterns of light to direct behaviour has provided selective advantages. In this sense, the qualification of stimulus energy as information—and hence direct perception itself—depends not only on aspects of the environment but also on aspects of the agent's perceptuo-motor system.

Environmental information lawfully specifies the layout of the environment in a one-to-one manner.[107] The specification relation obtains due to the nature of the causal relations existing between the structured energy in the medium and the environmental layout (e.g., the geometrical structure and texture of a surface being a cause of the structure in the light reflecting from it and/or diffracting around it). When a perceiver moves about in the environment (or conversely when the environment changes with respect to the perceiver), this transformation with respect to the perceiver's spatial position changes some of the light array

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[106] Although Gibson's description of direct perception varied, in what follows direct perception exclusively refers to the positive and negative characterizations of it that I provide below. I will assume that these characterizations would be accepted by many ecological psychologists as representative of Gibson's theory of direct perception.

[107] Although there are other accounts of neo-Gibsonian specification which allow for non-lawful yet regular specification relations (See Bruineberg et al., 2018), in what follows I will assume that direct perception involves one-to-one specification relations.

(stimulus) structure while some of it remains invariant. When revealed and detected, such invariant energy patterns lawfully specify the non-fleeting layout of the environment. An agent can come to perceive, for example, the unchanging geometric structure of a table due to invariant patterns in the light reflected by the table's surfaces as they move around it.

Crucially, environmental stimulus information is distinct from mere sensory stimuli arising at the inputs of afferent nerves. For example, the optic nerve can be stimulated by light at the retina but if that light fails to be *differentiated*, and hence fails to be structured, such sensory stimuli carry no information about the structure of the environmental layout (Gibson, 1979). It is important to note the more general point that the detection of environmental information for perception is a process that occurs across time. The idea is that perceptual systems (i.e., the perceptual organs in the active body), due to the ubiquitous presence of environmental information, continuously sample and actively adjust to the flow of environment specifying stimulus information. This may be contrasted with what Gibson identified as the traditional (i.e., indirect) view of perception. On such a view the notion of environmental information is absent altogether and instead perception is based upon the enrichment of current sensory stimuli (i.e., discrete 'snap shots') given stored snap shots of past stimuli and computational rules for combination and enrichment. Perception for ecological psychologists on the other hand is not based upon impoverished, discrete sensory stimuli but rather upon the flow of rich, environment-specifying stimulus information. Hence, the fact that direct perception involves action-driven transformation of the ambient energy array in order to detect environmental information means that present perceptual experience is not something that can be neatly separated from past perceptual experience, or as Gibson writes:

> "There are attempts to talk about a "conscious" present, or a "specious" present, or a "span" of present perception, or a span of "immediate memory", but they all founder on the simple fact that there is no dividing line between the present and the past, between perceiving and remembering.

> A special sense impression clearly ceases when the sensory excitation ends, but a perception does not. It does not become a memory after a certain length of time. A perception, in fact, does not have an end. Perceiving goes on" (1979, p. 242).

Direct perception is seen as an exploratory activity of detecting information in the environment *over time* – information that is not only determined by the structure of the environment but by the very organization of an agent's perceptuo-motor system.

Defined negatively, perception is direct just in case it does not involve the use of mediating information processing to enrich and/or disambiguate impoverished and sparse sensory stimuli with knowledge states. Knowledge states may be interpreted as those stored internal representational states that reflect a system's past sensory encounters with its environment, and which may be deployed in inferring current states of the environment. Gibson, identifying a commonality amongst indirect theories of perception writes:

> "All [indirect] theorists seem to agree that past experience is brought to bear on the sensory inputs, which means that memories are somehow applied to them (Gibson, 1979, p.253).

And again, pointing out what he takes to be the common flaw in indirect theories, Gibson suggests:

> "The error lies, it seems to me, in assuming that either innate ideas or acquired ideas must be applied to bare sensory inputs for perceiving to occur. The fallacy is to assume that because inputs convey no knowledge they can be made somehow to yield knowledge by "processing" them". (Gibson, 1979, p.253).

A key insight of ecological psychology is that the availability of behaviourally relevant environmental information obviates the need to deploy knowledge states (e.g., memory states) from which to infer the structure of the environment or the agent-relative value of what is perceived.[108] The pragmatic values of objects in the environment for a particular agent are not something that is added to or derived *ex post facto* from the objects perceived. The possibilities for action that an object offers – its pragmatic value or significance – is directly perceived *via picking-up* the appropriate self-environment information. Direct detection of information thus contrasts with the use of knowledge states to distil information from impoverished sensory stimuli. In other words, direct perception theory "does not have to have as a basic postulate the effect of past experience on present experience by way of memory" and hence an account of direct perception "does not need memory" (Gibson, 1979, p. 243).

Although representational memory states play no role in direct perception theory, the role of perceptual "learning" is acknowledged. Perceptual learning refers to "the improvement of perceiving with practice and the education of attention, but not by an appeal to the catch-all of past experience or to the muddle of memory (Gibson, 1979, p. 243). This kind of learning has been more recently fleshed out Jacobs & Michaels (2007) in their theory of *direct learning*. [109] The idea here is roughly that, like information for perception, there is detectable information in the environment for improving one's perception – information for learning that specifies the most useful invariants to detect relative to a given task. Learning and hence the improvement of perception and task performance is the result of the perceptual system's becoming attuned to better task-specific information. This results in the

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[108] In what follows I will focus upon memory states (short-term, working and long-term memory) as definitive of the kinds of acquired knowledge states that a theory of ecological direct perception bans in perceptual explanation. As such, I will hereafter use the terms *memory states* and *knowledge states* interchangeably unless otherwise stated. Moreover, knowledge states (memory states) should be distinguished from knowledge. In particular, where knowledge states are representational and are rejected as constitutive of perceptual processes, procedural "knowledge how" is thought to be compatible with direct perception (cf. Heft, 1989).

[109] The theory of direct learning is intricate and complex. Offering a detailed account of the theory however is beyond the limited scope of this paper.

new ability to perceptive features that were hitherto indistinct or that went unnoticed, a process which Gibson & Gibson (1955) described as the “education of attention”.

4.2.2 Affordance Perception – direct vs indirect

To see how the definition of direct perception—in conjunction with the theory of environmental information—applies to affordance perception, remember that affordances are defined by the structural and dynamically interacting aspects of the environment and the agent. Because affordances are properties of agent-environment systems, and assuming that both an agent’s capacities and the layout of objects in the environment are specified by information that an agent can—and does—detect, perceiving affordances directly is a matter of the mutual detection of *self-information* and *information about the environment*; detection of “higher-order invariants” (Gibson, 1979). For instance, one might detect invariant information in the light array specifying a certain horizontally situated flat surface with a particular surface area. Simultaneously, one detects invariant information from one’s own proprioceptors specifying one’s own weight, size, relative bodily position. Detecting these invariants together, depending upon whether the perceived area of the surface is compatible with the perceived bodily features, one may directly perceive that the surface affords sitting or lying down upon.

Direct perception of affordances, like perception more generally, according to ecological psychologists is something which does not involve the use of mediating memory states or information processing but is sufficiently accounted for by the pickup and exploitation of environmental information by perceptual systems. Perception of affordances and the layout of the environment are dependent upon both the structure of the environment and aspects of the agent-perceiver.

Moreover, perception of affordances, like perception of the environmental layout, may be improved via the process of direct learning, a process in this case where there is a change from the detection of less useful to more useful higher-order invariants to improve the performance of a given task.

In contrast to ecological psychologists, cognitive scientists remain silent on the notion of environmental information and its exploitation when investigating and theorizing about affordances. They have focused on affordance perception as a *representational* and *contextually-biased* process. Let's take each of these characteristics in turn.

A crucial distinction between indirect and ecologically direct affordance perception (and perception more generally) is the manner in which the notion of detection is spelled out. According to the direct view, when a perceptual system detects environmental information (and self-information), internal (brain) dynamics are said to *resonate* with that information much like a radio receiver resonates with certain frequencies bands of radio waves.[110] As Gibson writes:

> "Instead of supposing that the brain constructs or computes the objective information from a kaleidoscopic inflow of sensations, we may suppose the orienting of the organs of perception is governed by the brain so that the whole system of input and output resonates to the external information. (Gibson, 1966. P. 5).

Rather than using the non-representational notion of resonance, cognitive scientists studying affordances view the detection of affordances as enabled by causally responsive neuronal activation patterns in sensorimotor regions in the brain that represent affordances. As we shall see in more detail below, this

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[110] For a recent example of how the notion of resonance has been spelled out non-metaphorically see for example Raja (2018).

representational view of affordance perception is clear in Clark's characterization of predictive processing (2016a):

> "Here different (but densely interanimated) neuronal populations learn to predict various organism-salient regularities obtaining at many spatial and temporal scales. In so doing they lock on to patterns specifying everything from lines and edges, to zebra stripes, to movies, meanings, popcorn, parking lots, and the characteristic plays of offence and defence by your favourite football team. The world thus revealed is a world tailored to human needs, tasks, and actions. It is a world built of affordances—opportunities for action and intervention" (p. xv.).

One important motivation for representational accounts of affordance perception is that they appear well-placed to answer the question of how agents come to act upon only one of the many perceptible affordances that a particular object/event offers. The proposed solution brings us to the second characteristic of affordance perception (representation being the first) as construed by cognitive science: *top down contextual biasing*. To be sure, that affordance perception is sensitive in various ways to changing environmental and organismic conditions is agreed upon by both ecological psychologists (Heft, 1990; Rietveld & Kiverstein, 2014; Wagman, Stoffregen, Bai, & Schloesser, 2018) and cognitive scientists (Ambrosini, Scorolli, Borghi, & Costantini, 2012; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Costantini, Ambrosini, Scorolli, & Borghi, 2011; Pezzulo & Cisek, 2016). It is understanding the precise manner of how affordance perception is influenced by the manipulation of various contextual parameters that reflects the pronounced distinction between the perspectives of ecological psychology and PP towards affordance perception. Providing a direct perception account of context sensitivity is an important task for ecological psychology (Heft, 1990). This task is one of offering an explanation as to how the degree to which an object is perceived as affording some action is subject to contextual influences in a manner that avoids the use of mediating memory states in the explanation. On the other hand, context sensitive affordance perception from the perspective of cognitive science is explained by an ecologically indirect process of contextual biasing. This is a *top down* process whereby activated inner representations of affordances are modulated by acquired (subpersonal) knowledge stores and goals to determine which of the many available affordances in the environment will be acted upon.

For example, according to the “affordance competition hypothesis” (Cisek, 2007; Pezzulo & Cisek, 2016), affordance perception involves both the generation of top-down signals within the prefrontal cortex and basal ganglia which convey the most desirable actions and the representation of affordances activated along the dorso-ventral stream. The top-down signals, in addition to continuous bottom-up feedback concerning an agent’s current physiological state(s) (e.g., fatigued vs. not fatigued), mediate the competition for behaviour control between the many automatically activated affordances, resulting in the selection of one ‘winning’ affordance. Let us now look closely at a particular cognitive framework, *action-oriented predictive processing*, which exemplifies how a conception of affordance perception as representational and contextually biased (such as we find in the affordance competition hypothesis) may be implemented at the information processing level. This will put us in a better position to adjudicate, in section 4, the kinds of sensorimotor behaviours that are and are not susceptible to explanation in terms of the direct perception of affordances.

4.3 Action-oriented Predictive Processing – a brief overview

Action oriented predictive processing (hereafter referred to as predictive processing or PP) (Clark, 2013/2016a/2016b), is a cognitive framework which accounts for perception, action, learning, and decision making with the same overarching process of hierarchical prediction error minimization. According to PP, the brain instantiates a hierarchical *generative model* of the external causes of sensory state flows that are observed at the sensorium (including the sensory effects of the agent's acting upon its world). The brain's generative model, through a process of approximate Bayesian inference, engenders 'top-down' predictions about the kinds of sensory signals that are most likely to be encountered given the empirical priors (statistical 'beliefs') which the model has come to statistically encode over both phylogenetic and ontogenetic timescales. Predictions in higher cortical levels are generated and compared to ascending 'bottom-up' sensory signals at each respective level below. When predictions fail to accommodate sensory signals, residual prediction error (mismatch between the top-down prediction and the bottom-up signal) propagates upward and laterally along the cortical hierarchy. Prediction error is minimized in an ongoing and environmentally coupled process involving both altering predictions to accommodate error signals (known as perceptual inference) and altering one's relative bodily position in the environment so as to control and avoid sensory signals that would result in high levels of prediction error or to bring the sensory/error signals in line with current proprioceptive and exteroceptive predictions by engaging classical reflex arcs (known as active inference) (Clark, 2016a). Counter to the modular views of perception and action found in classical input/output models of cognition, perception and action in PP are viewed as a tightly coupled, inseparable process.

Although the fine-tuning and nuancing of predictions allows the generative model to capture the causal structure of the world, this process is not geared towards high-fidelity veridical perception of the world. Rather, the minimization of prediction error over the long run allows organisms to meet the dynamics of their milieus with adaptive, model-confirming behaviour. Unlike 'conservative' interpretations of predictive processing (see Hohwy, 2013), action-oriented PP sees "the prediction engine as fundamentally tuned to affordances and geared to the use of body, world, and action as means of simplifying inner processing" (Clark, 2019, p. 278). By showing how bodily, world-engaging action can often do much of the cognitive heavy lifting in error minimization, PP is claimed to offer a cognitive architecture that is consistent with many of the insights of both embodied and action-based theories of cognition (Clark, 2016a). For example, active inference in PP fits well with the notion common to both embodied cognition and action-based theories that cognition is not a process of reconstructing an inner model of the world that can be (eventually) traded-out for the real world. Rather, cognition for both PP and embodied and action-based theories is often a matter of the agent's coupling to the environment so as to bring about the kind of adaptive engagement required of a given task. Prediction error minimization in PP is fundamentally in the game of finessing successful adaptive behaviour.

In addition to hierarchical prediction error minimization, the central feature of PP that we will be concerned with is the notion of *precision weighting*. Sensory/error signals, when estimated to be reliable, are amplified (i.e., precision weighted) via the modulation of synaptic gain (Clark, 2016a). 'Reliability' here consists in having a higher signal to noise ratio and thus a higher measure of statistical certainty. However, given that what qualifies as noise and what qualifies as informative signal may be a relative to an agent's contextually driven goals, precision weighting may be understood as the encoding of context (Friston et al., 2012). Precision-weighted sensory and error signals drive model selection, controlling the relative contribution of various sensory modalities, in addition to controlling "the relative influence of prior expectations at different levels" (Friston, 2009, p. 299). It is in this manner that precision weighting determines which sensory channels are selected to influence (perceptual and active) inference and how endogenously generated predictions are balanced with incoming sensory signals (Parr & Friston, 2019)[111]. For example, if one has been primed to see faces and is then shown an illustration that ambiguously presents a face or the rear perspective of an Inuit in a parka (Figure 10), the visual data that has the greatest effect on model selection (face or

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[111] For a detailed account of the important distinction between precision weighting (i.e., gain control) and attentional salience see Parr & Friston (2019).

Inuit in parka) will typically confirm the priors that have been updated by priming: one will see a face as a result of the contextualization of the visual data harvested.

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Figure 10

Inuit-face Ambiguous Figure. Retrieved from https://www.illusionsindex.org/i/eskimo-face.

Precision weighting thus (when all goes well) helps to ensure that the sensory information that reaches higher levels of the generative hierarchy is the most “newsworthy” (Clark, 2013). Crucially for our purposes, precision weighting is not only relevant to model update for the task of inferring the causes of sensory signals but, also, for realizing preferred action outcomes through action policy selection. An action policy is a particular sequence of actions that is indexed across multiple timesteps.[112] Where there might be many action policies that would result in some preferred future outcome, only one of them might be the most effective at keeping long-term prediction error to a minimum. For example, there may be many actions that one could take to cross a busy street. Walking to the crosswalk, pressing the button, waiting for the pedestrian signal to turn green and then crossing however is more likely to avoid unwanted long-term prediction error than walking into the street, and dodging oncoming traffic. By integrating current sensory information with information harvested in the past through the updating of the priors upon which the best action policies are conditioned, precision weighting guides action in ways that are less likely to incur high debts of (possibly irreducible) prediction error over the long run.

4.3.1 Predictive Processing and Affordance Perception

PP, like ecological psychology, construes affordances as opportunities for action that the environment (i.e., objects and events) offers an organism; they are relations obtaining between organism-environment systems (Linson et al., 2018). PP, however, views affordance perception as a representational process involving the hierarchical prediction driven dynamics of the generative model. An affordance as represented by the internal dynamics of the agent encodes a high likelihood with respect to an action outcome conditioned on a given action policy “such that

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[112] More technically, action policies describe transitions from one state of the generative model to the next future state and are evaluated by how much their outcomes reduced the expected long-term average prediction error.

“affords” amounts to “offers a relatively sure bet”” (Linson et al., 2018, p.12; cf. Franchak & Adolph 2014). A particular chair is perceived as sit-on-able for a human agent because there is a high likelihood that, given the anatomical features and capacities of that agent (as encoded by the generative model), the chair perceived would support her/his weight were she/he to sit in it. Such automatic activation of multiple affordance representations may be construed as a process of responding to and picking-up sensory information that confirms the high likelihoods of action outcomes, allowing an agent to perceive the probable outcomes of possible actions as salient features of the environment. Such activation is, for PP, the result of a continuous, nuanced and active coupling between agent and environment; it is only through acting upon the world – minimising prediction error via active inference – that the kinds of causal structure that serves as evidence for affordances (and hence for the organism-environment system) is revealed. PP thus offers an implementational account of the contextual biasing of affordance perception, suggesting how an agent, despite the automatic activation of multiple represented affordances, comes to act only on one. By engendering top-down predictions elicited on the basis of priors about the most desired and probable action outcomes and current sensory evidence, the one affordance of the many available offered by an object in the environment that best suits the context is perceived as salient and acted upon.

The differences between the direct perception view and the view of affordance perception in PP appear pronounced. According to the former, environmental information specifying affordances is detected directly by the perceptual system, resonating with its internal dynamics without the need for representations and top-down modulation. According to the latter, affordance perception involves inner representations of affordances and contextual biasing of those representations by priors of the generative model – that is, it involves precisely the kinds of representational and intervening knowledge states that Gibson and his followers oppose.

Having shown how PP can deal with context sensitivity, let us now turn to a particular case of context sensitivity that will be instrumental in adjudicating whether direct perception approaches can explain context sensitive affordance perception without using something like PP's information processing apparatus.

4.4 Historical Context Sensitivity

I shall define historical context sensitivity (HCS) as the influence upon current affordance perception by a past encounter with an event/object that persists after an interruption in sensory contact with that event/object. The challenge that HCS poses to ecological direct perception is that there appears to be cases where differences in the perceiver's sensitivity to environmental affordances cannot be explained solely by appeal to the interacting dynamics of the current environmental information and the agent's capacities.[113] Instead, such sensitivity is most plausibly explained by appeal to the modulation of current perception by past environmental information, in a way that seems to require appeal to memory states that modulate the perceiver's sensorimotor relation to their environment.

To see what I have in mind, consider the following scenario. An empty ceramic coffee mug is heated to finger-searing temperature in an oven. It is then removed

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[113] To be clear, the distinction between "current" and "past" affordance perception here does not suggest that perception occurs at an instant; the ecological commitment to the claim that perception is a temporally extended process is compatible with HCS. These temporal indexes may be understood intuitively as marking perceptual episodes. Perception may "go on" as Gibson claimed but perceptual episodes as determined by the environment specifying information available to a perceptual system does not. For example, when walking through the park 15 minutes ago, I saw a black poplar tree. After having passed the tree and exited the park, there is no sense in which I still perceived that tree, nor do I *currently* perceive it; I did perceive it in the past, during the period in which its structure was impinging upon my sensorium.

by someone wearing oven mitts, placed on a serving tray, then brought and placed before two subjects – Mara and Mike – in a separate room. Crucially, only Mara has seen, via video monitor, the mug being heated in the oven and removed with mitts. There is, let us suppose, no visual information or other sensory variables in the environmental information available to Mara and Mike that specify the mug's hot temperature. Mike, having failed to see the mug being retrieved from the oven, will perceive it as graspable. On the other hand, to Mara, the mug will not be perceived as graspable per se but will be perhaps only perceived *as graspable with oven mitts* or *graspable in the near future* or more generally *as to-be-avoided*.[114] Moreover, suppose that while the mug was temporarily out of Mara and Mike's sight, it was swapped for a duplicate. Any mug sharing the same gross sensible features as the mug which Mara perceived on the video-monitor will be seen by her as *to-be-avoided*. What accounts for this difference between Mara and Mike in the way the mug is perceived given that there is no current visual information that specifies the temperature of its surface and that they both have, *ex hypothesi*, the same capacities? Can proponents of direct perception accommodate this difference in what the subjects perceive without appeal to intervening memory or knowledge states?[115]

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[114] A neo-Gibsonian might object to this description, countering that the grasp-ability of the mug is still perceived, but not as inviting or soliciting (cf. Rietveld & Kiverstein, 2014). This counter however merely re-describes, rather than removes, the difference between the two subjects that are in need of explanation.

[115] This is intended as a thought experiment. The characterizations of what the subjects will and will not perceive are intuitions that, I take it, should be shared among proponents of affordance-invoking views of perception across the board. This being said, there are ways of operationalizing affordance perception that could be used to see whether these characterizations apply. Describing such operationalizations however is something that is beyond the scope of this paper.

4.4.1 Functional Context and the Nested Affordance Strategy

Among extant direct perception strategies for accommodating the context-sensitivity of affordance perception, it seems to me that the most promising when it comes to accommodating HCS appeals to the notion of *nested affordances* (Heft, 1999; Wagman et al., 2018).[116] On this notion, Heft writes:

> "If an object's affordance can be based at times on its relationship to another environmental feature, it becomes clear that this higher-order relationship between 'focal' object and surround can specify the functional significance of the object on a particular occasion. Accordingly, 'context' can be viewed as potential higher-order information in the ambient array, which is available to be picked up, as opposed to assuming that contextual meaning is imposed on an object by means of mediating, cognitive processes" (1990, p. 281).

Due to the fact that affordances are *relational properties* of the agent with respect to the environment, as changes in both the environment and an agent's capacities take place, new affordances become perceivable (or hidden) to the agent. Moreover, different object configurations in the surrounding environment (relative to a focal object and perceiver) often result in higher-order relationships between

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[116] Another direct perceptual strategy that might be suggested to accommodate HCS relies upon direct learning (Jacobs & Michaels, 2007). It might be argued that Mara, when seeing the mug taken from the oven, learns which information specifying the mug's affordances is the best to use for completing the given task of appropriately handling the mug. However, the *temporariness* of Mara's perceiving the mug as to-be-avoided presents a problem for this response. For instance, 5 minutes after being taken from the oven, Mara would not see the mug as to-be-avoided any longer. Given that there is no environmental information that specifies the changing temperature of the mug in the scenario as described, such a change must be specified by changing self-information (i.e., a change in inner dynamics) in relation to environmental information. However, in suggesting that changing self-information specifies the mug's change in temperature over time (and hence change in affordances offered by that object) one suggests something that starts to look a lot like an ecologically indirect perceptual strategy – a strategy that helps itself to the use of temporarily sustained memory states to explain HCS.

those focal objects and other objects/events in the surrounding environment. These higher-order relationships specify nested affordances. For example, a spoon sat next to a bowl of soup might afford eat-with-ability, however the same eat-with-ability affordance is not available when a spoon is perceived next to a hole in the ground.[117]

How are such higher-order relationships perceived without deploying mediating knowledge of the associations between the environmental *relata*? The following passage from Gibson provides a clue:

> "[…] a unique combination of invariants, a *compound* invariant, is just another invariant. It is a unit, and the components do not have to be combined or associated. Only if percepts were combinations of sensations would they have to be associated. Even in the classical terminology, it could be argued that when a number of stimuli are completely covariant, when they *always* go together, they constitute a single "stimulus."" (Gibson, 1979, p.140-141).

The general idea here is that nested affordances can be specified by compound invariants, which need not involve additional processes of combination or association between the invariants standing in relation to one another. Rather, such compound invariants are *extracted as units*. The capacity to extract invariants as units itself may result from direct learning. Although invariants and affordances differ in that the former are not what are perceived but are what enable perception, we may apply a similar notion of being perceived as units to affordances that are specified by compound invariants as anchored in the agent's capacities.

The nested affordance strategy suggests that HCS may be explained in terms of functional context: Mara perceived a configuration of interacting affordances (i.e., a higher-order relationship). Assuming that the mug was the focal object (towards

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[117] This example is used in Heft (1999) to illustrate the notion of nested affordances and functional context sensitivity.

which her attention was primarily directed) and both the oven and oven-mitted-retriever were the surround, a higher-order relationship between the mug and the surround with reference to Mara's capacities specified the mug functionally on the occasion as affording heat and as currently to-be-avoided with bare hands. However, given that the earlier configuration of objects perceived on the monitor and the subsequent configuration of objects that both participants perceive are distinct, what is it about the *current* configuration that specifies – for Mara only – the mug as something that is to-be-avoided?

An empty mug on a tray is not the kind of nested affordance configuration that specifies the mug as to-be-avoided (this is why one of subjects perceives the mug as graspable). The perception of the mug in the prior configuration as to-be-avoided must influence how Mara perceives it in the current configuration. Pointing to this influence, however, shifts but does not solve the problem that HCS poses for direct perception theory. The difficult question for direct perceptual theory to answer is *how* perception of the prior configuration influences the perception of the current configuration. To claim that Mara's perception of the mug as to-be-avoided in the prior configuration is 'sustained' in perceiving the new configuration, is as unhelpful as the claim that after perceiving a spoon in relation to a bowl of soup as eat-with-able, the same eat-with-ability is sustained in virtue of subsequently perceiving that spoon next to a hole in the ground. The nested affordance strategy offers a convincing manner of accounting for how the affordances of objects depend upon and change with objects' surrounds; new higher-order relationships are obtained between objects and their surrounds in new configurations relative to an agent's capacities. What it does not offer is a manner of accounting for how previously perceived affordances are sustained over time despite the obtaining of new higher-order relationships amongst focal objects and their surrounds in new configurations. It does not account for HCS.[118]

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[118] Although direct learning may provide an account for why Mara perceives the mug as to-be-avoided in relation to its surround configuration (i.e., because her perceptual system has become attuned to picking up higher-order invariants in a particular object configuration) it fails to account

One potential response on behalf of direct perception approaches might be to combine the nested affordance strategy with an appeal to the spatio-temporal nesting of perceptible events. The idea here is that *some* events, like objects, offer affordances (Stoffregen, 2002). Given that events may be spatio-temporally nested within other global events (the global event of climbing to the top of a ladder may be parsed into component events of climbing each rung), the affordance that the global event offers (e.g., changing a light bulb) may be parsed into nested affordances that each of its constituent events offer (climbing upon third rung affords avoiding contact with a spider on second rung). Completing the global event often brings with it the affordances of its functionally nested components (climbing to top of the ladder affords avoiding contact with a spider on the second rung). With this in mind it might be suggested that the event observed on the monitor (the removal of the mug from the oven) and the subsequent event (the placing of the tray with the mug on the table) are both nested within a global event (the serving of the mug). Because the first component event affords being burnt by the mug, the global event within which that component event is nested also affords being burnt by the mug. Mara thus perceives a different global event and affordances than Mike does.

What however makes it the case that the event perceived on the monitor is part of one and the same event that ends with the mug on the tray being placed before the participants and not two separate unrelated events? For the nested affordance strategy with respect to events is only as good as our best account of what non-arbitrarily makes one event a component of a larger global event. One reasonable answer is *the continuity of the events as perceived*. In response to this suggestion, it may be asked what it is about the former event in the HCS example (the removal of the mug from the oven) that makes it a component of the global event (the

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for why perceiving the mug as to-be-avoided is sustained when the particular nested configuration of invariants that she has become sensitized has ceased to be.

serving of the mug)? The common invariants between the event perceived on the monitor and the subsequent placement of the tray with the mug before the participants are those in the visual array specifying the structure of the mug itself (its shape, texture, colour, etc). These common mug-specifying invariants however are not enough in any obvious manner to render the two events in which the mug is embedded as part of the same perceivable global event. Without another non-arbitrary way to account for what makes the former event a component of the higher-order relationship in the HCS experiment as described, there is no reason to think that two consecutive events form a global event. As such, neither applying the nested affordances strategy to objects nor to events explains why Mara and Mike perceive different affordances when presented with the same object or event configuration.

There is thus reason to think that HCS reveals an explanatory limit of direct perception approaches. This explanatory limit is particularly relevant to theories in cognitive science like PP which import the ecological notion of affordances and yet analyse affordance perception as a representational process. Rather than being a reason for such accounts to dismiss the concepts of (and motivations behind) direct perception theory altogether, HCS and the explanatory limit it identifies offers an opportunity for PP to re-evaluate the degree to which lesser demanding cases of affordance perception (e.g., relative to HCS) require the kind of top-down modulation that HCS demands. Understanding how PP accounts for HCS provides PP with an opportunity to not only look more closely and critically at its deployment of ecological concepts but, as I will argue, throws into relief some of its implicit ecological assumptions that accompany using ecological concepts along the way. Now let us return to PP to see how it accounts for HCS.

4.4.2 Accounting for Historical Context Sensitivity with Predictive Processing

PP accounts for HCS in the following manner: past perceived objects and events affect the amount of current gain on sensory signals in virtue of the updating of priors and precision estimates. The perceptual effects of precision estimates as regulated by updated priors are tantamount in this case to the effects of working memory. Working memory involves the transient maintenance of a representation of an initial sensory stimulus that can be used in the service of an ongoing task (Baddeley, 1986). This maintenance can be sustained even when sensory contact with that stimulus has been temporarily lost. In the PP setting, this functional characterization of working memory may be spelled out as a process of hierarchical, temporally structured prior 'belief' update. As Parr and Friston (2017) write:

> "working memory updating requires a belief that sensory data is precise, but that maintaining a representation in memory in the presence of distractors requires believing new sensory data is noisy and volatility is low. Another way to conceptualise this is to consider that [precision] modulation biases updating of beliefs (working memory) towards either the current beliefs about the environment, or towards the current incoming data from the sensorium. This fits comfortably with the view that working memory is an attentive process as resistance to distracting stimuli occurs when there is 'attentive' biasing towards current beliefs, ensuring the posterior beliefs are kept close to prior beliefs" (p.17).

When Mara sees the mug being taken from a hot oven with an oven mitt, her priors (with respect to the mug) are updated to reflect the increased likelihood of its surface radiating heat. It may be reasonably speculated that not only the kind of visual sensory signals expected from the mug will be given more precision, but also that the current flow of sensory signals originating from thermoreceptors are given more gain due to their being reliable indicators of the hot condition of the mug. Reframed in terms of sensory signal modulation, the mug's appearing graspable to Mike but not to Mara —despite the fact that the same visual information is available to both of them—is a consequence of Mara's having updated priors that make a difference to the precision weighting of sensory signals. Given the definition of working memory above, the difference that estimated precision makes in this context is a difference encoded in working memory. Like the effect that priming with faces has on what one sees in a bi-stable image of a face-Inuit, Mara's memory states act to disambiguate the cutaneous membrane-damaging mug that is present to her from a mug that affords 'grasp-ability'.

One might think that this is a straightforward victory for PP over ecological direct perception. In the remainder of the paper, however, I will argue that the discussion so far sets us up to see how PP is best construed as exploiting just the kind of environmental information that is at the heart of ecological psychology. This opens up a vision of PP as ecological in spirit, if not in letter. Getting clear on the role of environmental information exploitation in PP is important because it offers a way of making sense of how action-oriented PP, despite its use of inference, representation and models, may nonetheless fit with aspects of embodied and action-based theories of cognition (see Anderson & Chemero, 2019).[119]

4.5 Ecological Information Exploitation and Prediction Error Minimization

Given what has been said thus far regarding PP, it may be difficult to see where the notion of environmental information exploitation fits into its explanatory scheme. Scratching below the surface, however, reveals that PP, far from denying that interaction with a structured environment plays a role in perception and action,

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[119] To be sure, if environmental information exploitation is implicit in the PP story, then it stands that there is some kind of relationship between detected environmental information and the kind of (Shannon) information that is used to quantify prediction error in PP. Getting clear on the nature of this relationship is an extremely important task but one that unfortunately, for reasons of limited space, cannot be taken up here.

presupposes it within the kinds of prediction error minimization processes it posits. Recall that active inference, one part of the coupled process by which prediction error is minimized, is characterized as the controlled sampling of sensory information so that it conforms to proprioceptive and exteroceptive predictions. Such controlled sampling leads to prediction error minimization, however, partly in virtue of the fact that there is *regular structure in the environment* which predictive systems can exploit to control what is sensed. Clark (2016a) suggests as much when he writes:

> “The flow of sensation (bound, as we saw, in constant circular causal commerce with the flow of action) is predictable just to the extent that there is spatial and temporal pattern in that flow. But such a pattern is a function of properties and features of the world and of the needs, form, and activities of the agent. Thus, the pattern of sensory stimulation reaching the eye […] is a function of the lighting conditions, structured scene, and the head and eye movements of the observer” (2016a, 171).

The pattern of sensory stimulation carries information about the regular structure of the environment given that it is a function of the environmental properties and features.[120] Only by having regular effects upon an environment which itself is invariantly structured, can action states influence sensory states such that those sensory states have predictable (structural) trajectories.

To exploit the regular structure in the environment is, I suggest, to initiate actions that systematically reveal detectable invariant patterns of stimulus information. Detecting such information in turn nuances top-down feedback via updating predictions, making available affordances salient and influencing which

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[120] One manner of fleshing out the notion of ecological information as regular environmental structure is by using the methods of natural scene statistics (NNS) (see Orlandi, 2016). Much more can be said about how Orlandi’s analysis of NNS relates to the notion of environmental information exploitation in PP that I present here, however, given reasons of space this task cannot be taken up here.

affordances are exploited given current context. Thus construed, exploitation of environmental information is an implicit feature of the circular and coupled organism-environmental dynamics which underwrites the kind of prediction error minimization that active and perceptual inference describe (cf. Kirchhoff & Kiverstein 2019). Environmental information in the context of PP may be cast as the stable causal structure of the environment that generative models come to statistically capture via continuous coupled organism-environment interaction. The idea that organismic structural features (in this case hierarchically organized brain activity and morphology) come to capture nested structural features of the environment and that the environment comes to bear the mark of active agents could not fit more neatly with the Gibsonian idea of organism-environment mutuality. In other words, organism-environment mutuality may be cast simply as the fact that an organism is a generative model of its environment (Friston, 2013).

One might think that the attempt to incorporate a Gibsonian/ecological idea of environmental information into action-oriented predictive processing is in tension with the fundamental role of prediction error in the latter. The presence of prediction error suggests that sensory stimulus is ambiguous rather than something which specifies the structure of the environment in a one-to-one manner. For ecological psychologists sensory information is considered informative because of the lawful specification relation that exists between the structuring environmental layout and the structured properties of the ambient energy arrays; ecological information lawfully specifies such that if ecological information is picked up this guarantees direct perception of some invariant property of the environment by an organism. Because direct perception cannot go wrong (Michaels & Carello, 1981; Heras-Escribano, & de Pinedo, 2016), there is no encoded error and no need for processing that corrects error. If this is the case, then it seems that picking up environmental information should rule out prediction error.

This kind of worry however fails to recognize that perceptual inference is inseparable from active inference (Clark,2016a; Adams, Shipp, & Friston, 2013). In other words, although some of the stimulus energy (i.e., stimulation) that is detected might result in prediction error, that error may be reduced by moving around and engaging the perceptuo-motor system accordingly. With respect to affordances one might say that stimulation remains merely a *potential* higher-order informational relatum without the kind of extero-proprioceptive traffic that prediction-error-nuanced action that allows. Perception-action is a continuous and interrelated process in PP that couples the active agent with the environment (Clark, 2016a). This is very much in line with Gibson's claim that perceiving is a continuous "exploratory activity" of actively making the environmental information that is there available to detect (cf. Chemero & Anderson, 2019). Minimizing prediction error via perceptual and active inference is nothing other than actively harvesting *potential* environmental information and revealing available one-to-one relations between sources of information and the sea of structure in the energy array *over time and as needed*.

Extracting environmental information at some time step, t_n, I am suggesting, takes place as a result of reducing prediction error at multiple scales arising from (a) the detection of sensory stimulation at some earlier time step, t_{n-1}, that does not uniquely determine its cause *and/or* (b) the extraction of environmental information at t_{n-1} that is less relevant to one's current goals. Coupling to the rich environmental information that is both available and relevant to one's current goals is a feat, one that requires continuous engagement with a world that is constantly being revealed, sustained, and altered as a result of action. Inferential prediction error minimization may thus be cast as a multilevel and multiscale means of refining the pick-up of environmental information by which a perceiver comes to detect the kind of environmental information that is estimated to be most relevant to its current goals and physiological conditions. The PP story of perception-action does not end with error or with the pick-up of environmental information for that matter. It is an ongoing, world-engaging, circular process that is refined, adjusted and optimized along the way via the mechanism of prediction error minimization; action begets better perception and perception begets better action.

Despite these important commonalities, the nature of ecological information exploitation that I am arguing is implicit in PP departs from that in ecological direct perception in an important manner. Although minimization of prediction error may bring an agent closer to extracting information that lawfully specifies the features of the environment, prediction error needn't be fully minimized across all hierarchical levels and timescales in order for it to guide behaviour. Potential environmental information that merely has a high likelihood of specifying the environment's layout (with respect to an organism's capacities), can—and often does—get the job done for guiding goal-directed behaviour. The synthesis I am proposing suggests that PP agents often engage with the world via anticipating the obtaining of affordances prior to actually perceiving them - thanks to the probabilistic nature of generative models. Nonetheless, the kind of environmental information I have argued is usefully seen as implicated in PP is just the same relational, pragmatically meaningful and directly-specifying information we find in ecological psychology – only the way in which this information is revealed and exploited differs in PP. Thus, although PP is not ecological in letter given the central role of representation within the framework, the kind of environmental information exploitation which I have suggested is implicit in active and perceptual inference renders it, in an important way, ecological in spirit.

4.6 Conclusion

If what I have argued above is valid, and HCS does represent a limit of ecological direct perception, this of course has ramifications for ecological psychology, namely that its programme of direct perception cannot account for all cases of context sensitive perceptual phenomena. This claim is significant in its own right, challenging ecological psychologists to respond to HCS with other direct perception strategies than those I considered above. However, the above view of the relationship between PP and ecological psychology has potentially interesting implications for PP that I would like to close by considering.

The first implication is this: that HCS is an explanatory limit for direct perception may suggest that in cases where objects and their spatial configurations are less temporally nested, precision weighting in the form of working memory has substantially less influence upon how affordances are perceived. For example, seeing the affordance of tofu-eating via the visible configuration of two chopsticks and a small piece of tofu in a bowl may require less of this kind of precision weighting than perceiving a mug as to-be-avoided shortly after having seen it being removed from a hot oven. In the tofu case, something similar to the ecological nested affordance strategy may account for why the perceptible configuration specifies an affordance of tofu-eating: one perceives the configuration of two chopsticks as affording a manner of picking up food and delivering it to one's mouth. One perceives the affordances in this case as a unit.

From the perspective of PP this process may be re-described in terms of the engagement of a generative model that has been updated so as to be the predictive nexus between visual and proprioceptive information (i.e., kind of visual and proprioceptive information flow that would be most likely to arise given the kind of current visual and proprioceptive information flow conditioned on an eating action policy). The information in the visual array caused by the two chopsticks is extracted via perceptual and active inference over time in relation to proprioceptive information about one's own motor skills. This is not to say that precision weighting has no part in this process but that precision weighting *in the form of working memory* demanded by HCS is not required to perceive the functional affordance of the configuration as a unit; the generative model, through a process of active and perceptual inference, may extract the available invariant compounds as a unit. As we saw above, however, the extended temporality involved in the mug case rules out its straightforward treatment via the nested affordance strategy. Whereas cases of context-sensitive affordance perception involving limited temporal nesting may depend primarily upon fast and computationally inexpensive coupling to environmental information, we saw above that HCS demands a shift towards the use of updated prior ‘beliefs’ to drive behavioural response.

This brings us to a second and related implication. The idea that shifts in cognitive strategies– from direct coupling with environmental information to precision-weighted prediction error– can occur in response to varying contexts not only presupposes certain mechanisms are in place but that responding to these varied contexts is something that is adaptive for the kind of agent in question. The limits of direct perception are thus of interest for PP because they may help demarcate where distinct (yet interacting) kinds of mechanisms and processes get a foothold relative to the kinds of increasingly complex niches that predictive agents have evolved with. The use of precision weighting to increase the impact of priors on object perception over time I suspect may very well represent a kind of cognitive “transition marker” (Ginsburg & Jablonka, 2019), a feature that demarcates biological systems with working memory from those without it. This transition marker picks out a difference in the degree and manner in which environmental information is used relative to the degree and manner in which precision weighted prior ‘belief’ drives adaptive behaviour. Understanding the limits of direct perception might thus provide a valuable opportunity to come closer in understanding the kinds of environmental challenges that, to be met, require something more than online perceptual coupling with the structured environment. Environments that not only reward the perception of spatially nested affordances as units (or events) but the temporally distributed reidentification of nested affordances might thus exert a selection pressure on organisms to develop the more sophisticated modes of precision-weighting and behavioural control with which I have suggested that PP can accommodate HCS.

Let me sum up: one of the central tenets of ecological psychology is that all perception is direct. Action-oriented predictive processing however views such affordance perception and its context sensitivity as an indirect process involving the use of stored representational states. I introduced a particular case of context sensitive affordance perception, historical context sensitivity, and demonstrated how it may be elegantly accounted for with predictive processing's mechanism of precision weighting. I then argued that an ecological theory of direct perception lacks the resources to account for historical context sensitivity. Despite this being the case, the analysis of how predictive processing accommodates historical context sensitivity provided an opportunity to look more carefully at how action-oriented predictive processing implicitly deploys the core ecological notion of environmental information exploitation. I then suggested that prediction error minimization can be cast as a mechanism for tuning to ecological information. I closed by suggesting that the explanatory limits of direct perception as revealed by HCS should be of independent interest to PP. Understanding the limits of direct perception may very well help to understand a subtle and gradual transition in predictive processing – a transition from the use of fast and frugal environmentally coupled cognitive mechanisms as a means of dealing with the uncertainty of the 'here and now' to the deployment of decoupled working memory to cope with increasingly complex environmental conditions.

This chapter has thrown light upon the phenomenon of HCS and has argued that the kind of precision weighting required to account for it may very well demarcate a distinctive mode of cognition that may not be shared with simpler organisms, the adaptive behaviour of which relies to a larger degree upon online coupling to environmental information. In the next chapter, I turn to mental imagery, a phenomenon that is typically assumed to be exclusively offline. Elucidating a particular kind of mental imagery generation, "comparative mental imagery generation", I argue that this assumption may be challenged when the ecological notion of environmental information is broadened to include "variant information".

Chapter 5

Coupling to variant information: an ecological account of comparative mental imagery generation

Abstract

Action-based theories of cognition place primary emphasis upon the role that agent-environment coupling plays in the emergence of psychological states. *Prima facie*, mental imagery seems to present a problem for some of these theories because it is understood to be stimulus-absent and thus thought to be decoupled from the environment. However, mental imagery is much more multifaceted than this “naïve” view suggests. Focusing on a particular kind of imagery, comparative mental imagery generation, this paper demonstrates that although such imagery is stimulus-absent, it is also stimulus-sensitive. Exhibiting stimulus-sensitivity is sufficient for a process to qualify as coupled to the environment. The notion of *variant coupling* is explicated as the coupling of a cognizer’s perceptual system to variant environmental information. By demarcating the categories of stimulus-absent and stimulus-sensitive cognition, and variant and invariant coupling, this paper expands the conceptual apparatus of action-based theories, suggesting not only a way to address the problem that comparative mental imagery generation presents, but perhaps a way to account for other forms of imagery too.

5.1 Introduction

Action-based theories of cognition (Gibson, 1979; Varela, Thompson, and Rosch, 1991; Clark, 1997,2016a; Ballard, 1997; Cisek & Kalaska, 2010; Pezzulo & Cisek 2016) conceive of perception, cognition, and action as a continuous and mutually influencing process, the ‘function’ of which is to guide interaction with an everchanging yet structured environment. Action-based theories may be contrasted to traditional serial information processing views, which conceive cognition primarily as a means of constructing an accurate description of environmental states. Although there is disagreement amongst action-based theories as to how (and the degree to which) agent-environment interaction is involved in the emergence of cognitive states, these approaches are unified in the importance they bestow upon coupled interaction with the environment. Some forms of action-based theory (e.g., traditional ecological approaches and some enactive theories), taking a wide explanatory scope, attempt to account for the majority of cognitive processes in terms of ongoing agent-environment coupling.[121] At first blush, these wide-scope action-based theories are faced with a serious problem when attempting to account for mental imagery. Like other offline phenomena, mental imagery provides cognizers with the means to explore possible behavioural outcomes prior to engaging in action, thus arriving at an ‘optimal’ behavioural choice (relative to one’s goals) in an energy efficient manner. Given its status as an offline phenomenon, mental imagery is commonly seen as

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[121] Those theories which I am calling wide-scope action-based theories go beyond making the weak claim that agent-environment coupling *mediates* higher forms of cognition (i.e., that higher forms of cognition such as thought or imagination come about in virtue of the covert, ‘as if’ deployment of the same sensorimotor mechanisms that would occur were actual agent-environment coupling were occurring). In contrast, wide-scope action-based theories claim that, like perception and action, many cases of higher cognition emerge from agent-environment coupling.

stimulus-absent[122] and thus decoupled from the environment (Pezzulo, 2017; Foglia & Grush, 2011). For this reason, any action-based account of imagery in which ongoing coupling is deemed essential seems deeply flawed. However, mental imagery is much more multifaceted than this “naïve” view suggests.

The multifaceted nature of mental imagery is exemplified particularly well when considering one intriguing form which involves the deployment of imagery in the service of visual comparison tasks with features of perceived objects. For example, one might be given the task to look at an object, generate an image with the same dimensions and then compare image dimensions with those of another perceived object. Such a task, for instance, might involve comparing the size of one box located in the left corner of a room to another similarly sized box located in the right corner of a room in order to know whether or not the leftmost box would fit inside of the other. This particular kind of image generation, what will be referred to as *comparative mental imagery* generation (CMIG), is striking for the reason that, upon close analysis, it challenges the orthodox view in cognitive psychology that all mental imagery generation is environmentally decoupled. In the first part of this paper I will argue that, because the imagery generated during CMIG remains *sensitive to the stimulus dynamics of the environment*, CMIG is both an offline and coupled process.

To do this, this paper argues that CMIG is both influenced by incoming sensory stimuli and may prompt image maintaining behaviour. Possessing this behaviour-eliciting sensitivity to environmental stimuli is sufficient for this kind of mental imagery generation to qualify as what I will call the process of *variant coupling*. Building on the notion of stimulus sensitivity, this paper offers an ecological account of the kind of coupling involved in CMIG. By illustrating how perceptual systems may couple to variant information in the environment, thus allowing for continued imagery maintenance despite ongoing encounters with disruptive

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[122] More will be said about the notion of stimulus absence below.

stimuli, the ecological account of CMIG demonstrates that action-based accounts should adopt a richer taxonomy of cognitive processes than a standard online/offline bifurcation, if they are to make sense of phenomena like CMIG. By demarcating the categories of stimulus-absent and stimulus-sensitive cognition, and variant and invariant coupling, this paper expands the conceptual apparatus of action-based theories, suggesting not only a way to address the problem that stimulus-absence presents for comparative mental imagery generation, but also a way that action-based theories may possibly account for other forms of stimulus-absent imagery.

This paper is organised as follows: after defining on and offline cognition from the theoretical perspective of action-based cognition, *section 5.2* provides an example and an analysis of CMIG. Using this CMIG example, *section 5.3* introduces the notion of *stimulus-sensitivity* and argues that exhibiting stimulus-sensitivity is sufficient for a mental state/process to be coupled to the environment. *Section 5.4* proposes an ecological account of *variant coupling* involved in CMIG. *Section 5.5* sketches a more fine-grained taxonomy of offline and online cognitive phenomena based upon the notions of variant and invariant coupling/decoupling and summarises the theoretical gains that this taxonomy affords for action-based theories.

5.2 Online and Offline Cognition

Within the context of action-based theories, as in the rest of cognitive psychology, the terms *online* and *offline* are readily accepted to demarcate two distinct cognitive modes (Clark, 1997: Pezzulo, 2017; Bickerton, 1996). Online cognition is characteristically understood to be *stimulus-based* (Pezzulo, 2017) or equally, causally dependent upon the task relevant stimulus features in the environment.

One might understand causal dependence here in the context of experiential states or processes as follows:

> Some psychological state, *S*, is causally dependent on state of affairs, *O* if:

a. were *O* not present, *S* would have failed to arise &
b. were there a registerable difference in *O*, then there would be a difference in *S*

Where (a) expresses a Lewisian (1973) counterfactual condition on causal dependence and (b) narrows the relevant causal dependence down to covariation of psychological states with environmental states by introducing a counterfactual conditional that takes a registerable difference[123] in O as an antecedent and a difference psychological state as a consequent.[124]

Importantly, action-based theories characterize online cognition as a kind of causally coupled interaction with the environment. An agent may be said to be coupled to the environment when her behaviour with respect to some task-relevant environmental feature brings about changes in the environment (or changes in relation between environmental features and the agent), which in turn modulate that agent's sensory states (i.e., input) acting to guide subsequent behaviour and constraining subsequent sensory states.[125] Coupling requires mutually ongoing causal activity between two or more systems over time. In the case of online cognition, those two systems are the external environment and the cognizer whose

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[123] Registerable difference is determined by the sensitivity of the type of perceptual system in question. It will suffice for the purposes of this exposition to assume this to be individuated by species.

[124] This is a mere suggestion as to how one may construe causal dependence of experiential states upon environmental states. If one is not satisfied with these particular conditions, then one is free to replace them with one's best conditions on causal dependence.

[125] Mathematically, this may be described in terms of a series of differential equations in which the changes in any one of the variables that is a constituent of one equation are reciprocally describable as a function of the changes in the other equation's variables. See Chemero (200) for an in-depth account of agent-environment coupling using the variable *tau*.

continuous state changes— understood respectively as *environmental states* and *internal, action* and *sensory states*—are mutually influencing and hence provide mutual information about one another (Jost, 2015).

Although there is disagreement amongst action-based theorists as to the details of how offline phenomena come about, it is agreed upon that offline cognition refers to phenomena which are *stimulus-absent*. The generation of the mental activity yielding offline phenomena is said to be largely spontaneous and thus both *causally independent* and *decoupled* from task relevant stimulus features in the environment. It follows that in such episodes of cognition offline states and environment states fail to provide mutual information about one another given that the activity resulting in offline states stops short of acting on the environment and receiving environmental feedback. Whilst offline states such as dreaming and contemplating non-existent entities (e.g., having thoughts about unicorns) might fail—at least in any direct way—to hinge upon prior environmental challenges encountered, many offline phenomena may be seen as “systematic explorations to problems set by experience” (Gerrans, 2007, p. 46). In other words, it is typical of a wide range of offline phenomena that they are deployed in solving problems which a cognizer may initially be presented with online. They provide an efficient way to explore behavioural options—often future oriented—thus avoiding costs in the form of time and energy-consuming, ‘real-time’ action or environmental exploration. Some further examples of offline phenomena are:

- *Mentally navigating* a route which has previously not been taken
- *Mentally rehearsing* a sequence of dance steps without carrying them out
- *Imagining* how a particular table would look in one’s parlour prior to buying it

With the online/offline distinction to hand, let’s move onto CMIG. CMIG is an example of an interesting form of mental imagery which illustrates that not all imagery generation is decoupled from the environment. In closely examining CMIG, it will be suggested that the stimulus-absent vs stimulus-based means of analysing cognition overlooks an important concept, that of *stimulus-sensitivity*. Because mental imagery generation may be consistently stimulus-sensitive and stimulus-absent, and (I will argue) stimulus-sensitivity is a way of being causally coupled to the environment, comparative mental imagery generation simultaneously involves decoupling and coupling. This is a significant result particularly for wide-scope action-based theories given that it provides a means of substantiating the claim that higher cognitive states like mental imagery involve *ongoing* agent-environment coupling.

5.2.1 Comparative Mental Imagery Generation

To understand what CMIG is, imagine a disk pairing game. You are presented with a table upon which are two rows of five disks of various sizes. The two rows are separated by a distance of one metre (or any approximate distance where you cannot view the rows simultaneously by saccades alone). Some of the disks are of noticeably different sizes and others with a mere difference of less than a centimetre (see Figure 11). The aim is to form pairs of disks from each row by sameness of size as quickly as possible. If you were to compare the size of two discs by actually placing them adjacent to (or atop) one another and looking for a noticeable difference, you would be engaging in real-time, online cognition. Offline cognition, however, might take the form of your *mentally comparing* the size of one disc with another by holding an image of the disk in mind, while looking at the disk dimensions in the adjacent row.[126]

Figure 11

Disk Pairing Game: the aim is to pair the disks from each row according to sameness of size as quickly as possible.

Let’s focus on some of the characteristics of offline cognition that are brought out in this example. Introspection reveals the following: during the game, a disk’s dimensions (i.e., size) are perceptually sampled, an image is generated and held fixed, transposed to a different location and tacitly compared to the size of a disk that is perceived online. Thus, despite their being derived from a perceptual encounter with the disks, the disk images elicited are *stimulus-absent*. That is, once the disk is perceptually sampled, the maintained image becomes decoupled from the disk it was sampled from, and thus no longer under the causal influence

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[126] For a classic comparative imagery study involving mental rotation, see Shepard & Metzler (1971). Although it involves 3-D manipulation, something which is much more complex than holding the disk size fixed and transposing it across one spatial dimension for comparison, the Shepard & Metzler mental rotation task may be nonetheless considered a form of CMIG. This is because the mental rotation task, although it involves 3-D rotation, requires holding a generated shape fixed in order to compare it to another shape that is seen online. Rotation may be seen as another manner of mentally transposing an image, albeit a spatially complex manner placing a higher requirement upon working memory.

of the disk. For instance, subsequent to sampling and maintenance, one may certainly break the disk without breaking the image. Importantly, this is illustrative of a case in which the mechanisms for generating and maintaining stimulus-absent images are deployed simultaneously to those that are being used for online perception; a capacity that falls out of the fact that mental imagery in a particular modality and perception in the corresponding modality may occur concurrently (Nanay, 2017). For the disk image to be used in a comparison task requires both the image and disk percept to be used concurrently.

Such simultaneous deployment should be expected given the general consideration that offline cognition is often used in the service of solving problems which an organism encounters in real-time (Gerrans, 2007) and that real-time problems often require constant reference to those environmental features from which the problems stem. Furthermore, it has been established by a range of neuroscientific studies that imagery and perception deploy much of the same neural circuitry (Kosslyn,1978, 1980, 2005; Farah 2000), supporting what has become known as the continuum thesis[127]. This thesis, which is assumed true within the cognitive science of mental imagery (Thomas, 1999), often begins with the evolutionary assumption that more complex cognitive capacities such as mental imagery generation developed from simpler perception-action capacities (Cisek & Kalaska, 2014; Pezzulo & Cisek, 2016). At least one version of the thesis then goes on to claim that mental imagery generation makes use of some of the same processing that is deployed in perception with the exception that in imagery generation the processing that would normally lead to perception is somehow inhibited (Degenaar & Myin, 2014).

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[127] The continuum thesis that will be referred to throughout this paper should not be confused with the more controversial *philosophical continuum thesis*. The philosophical continuum thesis states that there is no qualitative difference between mental imagery and perception, but rather a mere quantitative difference. I am greatly indebted to an anonymous reviewer for bringing this distinction to my attention.

If imagery makes use of much of the same neural processing as perception, we might expect that one kind of phenomenon could affect the other. This suggestion is supported by the fact that impairments in one domain can often be accompanied by impairments in the other (Farah, 2000). Early research by Bisiach & Luzzatti (1978), for example, discovered that patients suffering from unilateral neglect also tend to neglect the corresponding area of their mental imagery. Additional evidence comes from the noting that making random eye movements disrupts visual imagery (Thomas, 2010) and imagining a particular type of object involves making similar saccadic eye movements to those that one would make when perceiving that object (Fourtassi, Hajjioui, Urquizar, Rossetti, Rode & Pisella, 2018). [128] In the next subsection, I will attempt to specify just how the stimuli encountered in perception could affect mental imagery.

5.3 Stimulus-sensitivity

The disk pairing game exemplifies CMIG. This domain of offline cognition, I will argue, makes it evident that the online/offline taxonomy as based upon the notions of stimulus-based and stimulus-absent is underdeveloped. CMIG is a temporally extended process in which the spatial comparison of generated and held imagery with spatial environmental features requires the use of both off and online mechanisms. Given that perception requires the processing of environmental stimuli, it may be asked whether the stimuli thus processed have any causal effect upon the accompanying maintained visual imagery?[129] In other words, although

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[128] Fourtassi et al. (2018), by applying a bi-dimensional regression model to eye-tracking data collected during an imagery task (i.e., imagining different towns in France) were able to confirm that saccadic gaze patterns closely reflect spatial dimensions of relative town locations.

[129] This question is different than that of whether or not the general processes involved in perception, such as random eye movements, affect imagery, something which—as pointed out

the imagery associated with CMIG is stimulus-absent (i.e., causally decoupled from the sampled source) is it possible that the held imagery is sensitive to impinging visual stimuli encountered during the comparison task? It is by posing this question that the notion of *stimulus sensitivity* reveals itself.

Let us define stimulus sensitivity as follows:

> A mental process is stimulus sensitive just in case:
>
> (1) its individuating features are subject to being affected by incoming stimuli and
> (2) it is likely to elicit adaptive-control responses when such stimuli threaten to degrade the imagery being generated/maintained.

To take an example from the disk pairing game, the mental image is a blue disk of certain size and lasting in its vivacity and dimensions over a certain period of time corresponding to the task at hand. Condition (1) on stimulus sensitivity requires that such an image's individuating features be subject to influence by visual stimuli. Where individuating features are those subjective properties of an image which qualify it as the image token that it is. Let's imagine that after sampling one of the disks on the left-hand side of the table and holding that image, an intense flash of light occurs, hitting your eyes as you direct your head and eyes to the disks on the right-hand side of the table. Were this light flash to affect the blueness, size, or shape of the held image then such an image would satisfy condition (1)[130].

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above—has been empirically supported. This question is particularly about the influence of environmental stimuli upon imagery.

[130] That this could be the case presupposes that an intense flash of light hitting one's eyes typically blurs online vision and that the affected processes are the same exploited by offline

Condition (2) requires an image to be likely to elicit behavioural responses that aid in the maintenance of those individuating features of an image. The notion of adaptive-control here is one borrowed from control theory (Pezzulo & Cisek 2016; Ashby, 1952). It may be roughly thought of as a means to keep a certain control variable in a system within a restricted range by actively controlling the feedback into the system. In the disk pairing game, the control variable may be construed as one of the image individuating features of any sampled disk. Adaptive control responses would be those which the imager would deploy (tacitly or non-tacitly) in order to maintain that feature during the comparison task. If there were certain behaviours that were likely to be elicited for this purpose, then condition (2) would be satisfied. Are there any reasons to believe that mental imagery satisfies either of these conditions on stimulus sensitivity? Let's look at each condition respectively.

Lending support to the satisfaction of condition (1) we may look to luminance effects studies by Keogh & Pearson (2014). It is well established that when a subject is told to generate a mental image of one of two binocular rivalry images, say a green Gabor patch, and then shown a binocular rivalry display with opposing red and green Gabor patches, the congruent green patch in the display will be experienced as more dominant (Keogh & Pearson 2011; Sherwood & Pearson, 2010). By increasing background luminance during the generation of a mental image, Keogh & Pearson have shown that congruent images presented subsequently in a binocular rivalry display were less dominant for good imagers. This suggests that "incoming visual information, which has obligatory access to early visual areas, can interfere with […] internal sensory representations" (Keogh & Pearson, 2014:10). In other words, online stimuli can—in some cases—degrade imagery; an unsurprising result, given the continuum thesis described above (Thomas, 1999).

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vision. I am indebted to an anonymous reviewer for the suggestion to clarify this point in more detail.

What about condition (2)? One way to frame the question about satisfying (2) is to ask *what can an agent do to avoid image degradation?* In responding to this question, I will focus upon two kinds of responses: saccadic eye movement and pupilar constriction. These responses offer indirect—though, I suggest, compelling—support for the satisfaction of (2) based on empirical studies. In coming to understand how saccades may be used to avoid degradation, it is helpful to keep in mind the seminal research on eye tracking and top-down influence by Alfred Yarbus (1967). In one famous experiment, Yarbus, used a painting depicting a family gathered in a parlour as a visual stimulus. After an initial viewing, before which no particular instructions were given, subjects were assigned various tasks to carry out prior to each subsequent 3 minute viewing (e.g., "estimate the material circumstance of the family", "remember the positions of the people and objects in the room", "Surmise what the family had been doing before the arrival of 'unexpected visitor'"). Whilst carrying out these various tasks, the subjects' saccades were tracked. It was found that the saccadic patterns varied significantly with the kind of task assigned, thus providing evidence that *saccades can be driven to pursue meaningful information given the nature of the task*. Saccades, it turned out, are not just passive responses, but are under the influence of 'top-down' control , deeply reflecting the nature of the goals to be achieved.[131] With this in mind, I would like to suggest a variation on Yarbus's findings that will underwrite a response to the question about (2) posed above, viz., *saccades can be driven to avoid disruptive visual stimuli given the nature of the task*.

Recent research by Kilpeläinen & Theeuwes (2016) supports this claim. After establishing a penalty zone (an area which subjects would be financially penalized for fixating upon) in a visual display and instructing subjects to locate cues that

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[131] Although today this conclusion is not surprising, in 1967 it was. Three decades prior to Yarbus' research into active vision, work by G.T. Buswell (1935) confirmed that the eye movements are under the influence of goals. However, due to the fact that his experiment featured different kinds of tasks requiring different kinds of cognitive faculties (e.g., remembering vs judgement), Yarbus managed to demonstrate not only that goals influence saccades but that differences in goals are systematically reflected in saccadic activity in a fine-grained manner.

would be intermittently flashed in the same display, Kilpeläinen & Theeuwes found that saccades can be flexibly adapted to changing environmental circumstances to improve reward outcome. Given that improving reward outcomes in this experiment is equivalent to decreasing penalization outcomes, these results suggest that the bodily exploration of the environment involved in perception might be adaptively shaped both by what is desired and what is not desired: the result being the avoidance of undesired stimuli. Given that this is the case, an account of CMIG as a stimulus-sensitive process predicts that in mental imagery cases subsequent to exposure to image degrading stimuli (e.g., high luminance surfaces), a subject will reduce the number of saccades to locations containing such stimuli in order to improve the task outcome.

Pupilar dilation provides striking additional support for the satisfaction of condition (2). Studies by Binda, Pereverzeva & Murray (2013) have shown that pupils constrict when subjects are merely looking at photos of the sun. These findings suggest contextual expectations elicit pupilar response and modulation of sensory processing. Returning to the context of mental imagery, given these results one might expect that after learning which stimuli (or changes in stimuli) predict the presence of high luminance conditions, an agent’s pupils might constrict to avoid the degradation of imagery and dilate otherwise (say, for further sampling during CMIG). This goes beyond mere anticipatory pre-emption in that some stimulus is required as a predictor of the upcoming increase in luminance (much as the image of the sun serves as a predictor of vision-degrading brightness). It is this predictor stimulus that is necessary to drive behaviour in ways that help stay within a certain imagery-friendly luminance range. Thus, such constriction and dilation would have to be a measured and delicately balanced response; one influenced both by top-down and bottom-up processing.

Taking into consideration both luminance effects on imagery and evidence that saccades and pupilar responses may be contextually driven to avoid anticipated image-degrading stimuli (or equally driven to couple to stimuli that is nondegrading to imagery), gives strong, though indirect, support for the hypothesis that CMIG is stimulus sensitive. To be sure, there are other instances of visual mental imagery generation in which an agent is not subject to the influence of visual stimuli. For example, were one to wear an eye mask blocking out all visual stimuli, luminance effects (in addition to all other possible light stimuli effects) would be null; there would be no occasion for visually based adaptive-control responses. In such a case, it might well be that visual mental imagery generation is *stimulus-insensitive*.[132] However, since CMIG by definition involves comparing imagery with perceived objects and thus requires an openness to incoming visual stimuli, the imagery generated and maintained during CMIG remains sensitive to visual stimuli which, via adaptive control, are kept within a limited, image-conducive, range.[133] Stimulus sensitivity thus implies that the processing underlying CMIG remains causally coupled to the environment. CMIG piggybacks on stimulus-based perception but is a distinct offline process.

Crucially, this *opens up the theoretical space* for the images in CMIG to be consistently both stimulus-absent (i.e., causally decoupled from the environmental source of their phenomenal character) and yet stimulus-sensitive (i.e., causally coupled to visual stimuli encountered during the visual task). Accepting this kind of analysis of CMIG as plausible, however, is to a large extent dependent upon providing an account of what it is that visual systems are coupling to. In the course of addressing this question in the next section, some important further details about stimulus-sensitivity will emerge.

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[132] It is an interesting and open empirical question whether or not (or the degree to which) non-visual exteroceptive modalities such as sound have any significant effect upon visual mental imagery. That this is the case with respect to auditory stimuli seems to me to clearly to be the case, particularly with respect to sound effects. See Miller & Marks (1992) for evidence as to how radio sound effects affect the elicitation of visual imagery.

[133] This claim is consistent with the further claim that saccades reflect ‘encoded’ spatial relations and hence are sensitive to various spatial dimensions which have been encoded into memory. The point again is that saccadic behaviour during imagery maintenance is not only driven by top-down, inner-dynamics but also bottom-up, environmental dynamics.

5.4 Coupling to Variant Information

What does a cognizer couple to during CMIG? In answering this question, it will be helpful to examine the kind of coupling relata that an ecologically informed theory of active cognition is committed to. The reason for this is that ecological theories place an emphasis upon the environment as playing an indispensable role in cognition and thus such theories offer the most richly developed framework for thinking about coupling amongst action-based theories. Drawing on Gibson's ecological psychology (1979) one form of enactivism (Kiverstein & Rietveld, 2018; Bruineberg et al. 2018; Rietveld & Kiverstein, 2014) understands coupling to be a relation between inner dynamics and the environmental information. If environmental information is given its usual gloss of being invariant patterns that specify the layout of the environment (Gibson, 1979), then it is by coupling to invariant information that organisms perceive the environmental layout specified by that information.

With this in mind, there is a clear distinction to be drawn between invariant information and the stimuli involved in stimulus sensitivity. Given the description of stimulus-sensitivity provided above, it seems that the kind of stimuli that affect the phenomenal character of imagery and elicit response does not specify the environmental layout. Returning to the Keogh & Pearson (2014) study, although the high luminance light that disturbs imagery generation originates from a surface, the light itself does not specify that surface. In Gibson's (1979) terminology, such light stimulus is not "ambient" but merely "radiant" and thus falls short of carrying invariant information. Given that this is the case, the latter does not specify unchanging environmental structure. So, whatever the kind of coupling that stimulus-sensitivity implies is, it is distinct from that which occurs in perception.

The coupling that ecologically informed theories have traditionally used in accounting for perception is understood to involve information that specifies the environmental layout or *what* actions the layout offers (i.e., affordances). However, the environmental *relata* which stimulus-sensitivity involves, because of being behaviour guiding nevertheless serves as information for the perceptual system. In the case of CMIG, the visual system is coupled to meaningful, non-homogenous stimuli that are instructive as to *how to behave* relative to the task at hand.[134] Alone, high luminance radiant light does not serve as information, but given the limited range of available stimulus conditions within which imagery can be maintained *and* the location of the perceiver in relation to varying environmental stimulus conditions, such radiant light stimulus is informative: it specifies where not to saccade from *this* location.

One might object, arguing that such information—call it 'variant information'—seems nonetheless unlikely to be the kind of thing which could be the environmental *relata* that underlies coupling. For it would seem odd that the occasional encounter with high luminance conditions and the elicited response to avoid them could be considered anything other than a temporary coupling and immediate decoupling from such stimulus conditions. In other words, it seems that the visual system is adapting in ways so as to remain *decoupled* from high luminance, image degrading stimuli. In response to this, one need only be reminded that light conditions are continuously fluctuating in ways that are sometimes better or worse for imagery maintenance. During CMIG the visual system is constantly engaged in an attempt to stay coupled to the range of stimulus conditions that are best suited for imagery maintenance and it does this by coupling to and decoupling from degrading stimuli exogenously encountered.

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[134] One way of conceiving the difference between those things that are specified affordances and those things which variant information specify may be brought out respectively in the vocabulary of "action selection" and "action specification" (Pezzulo & Cisek, 2016). This may be seen as a difference between selecting amongst those activities (i.e., *what*) the environmental layout offers (e.g., sitting, standing, walking through, etc.) and the specification of an action that describes *how* one's body must behave to successfully bring about a selected action.

Thus, it may be argued, that the visual system does not couple to high luminance surfaces *only* to decouple from them, but, instead, when such conditions are encountered, by responding in ways to avoid them (or adapt to them), the visual system remains coupled to the stimulus conditions which are conducive to imagery maintenance. Variant information in this sense guides the visual system back to the 'optimal' conditions, constraining the task driven saccadic patterns that unfold during CMIG.

One may think about this process analogously to descending an unfamiliar staircase in the dark by sweeping a foot along until it meets the next stair below. Failing to encounter a surface upon which to shift one's weight, one continues to sweep and until such a surface is detected. A sweep that fails to detect anything is nonetheless informative as to where not to place one's weight. On the other hand, when one detects a surface, one knows where to shift one's weight. Through a series of such moves one descends the darkened staircase, staying balanced upright along the way. Similarly, variant information guides the visual system in both *how* and *how not* to behave given both the task at hand and the location that one occupies.

The specifying role of this ecological variant information is made explicit in the following passage from Warren (2005), who, drawing a comparison between it and the role of invariant information, writes:

> "Reciprocally, the varying spatial relation between objects and perceiver is specified by the *perspective structure* of stimulation. This corresponds to the view of the environment *from here*, which locates environmental surfaces and objects relative to the perceiver, and the perceiver relative to its environment" (Warren, 2005, p. 343).

This perspectival structure is what Gibson (1979) referred to as *propriospecific information*. Since it specifies something about the perceiver's current position relative to the environment, it may be thought of as providing her with the kind of indexical information required to direct her body in ways that *would* change her relationship to the environment. Self-specifying variant information and environment-specifying invariant information, according to Gibson, are complementary (1979, p. 183), with each reciprocally determining the other. Importantly, neither kind of complementary information is something that one is aware of. One is, however, aware of those things which the information types specify: the stable environmental layout (e.g., the non-changing proportions of a table's rectangular surface as one approaches it) and the flowing perspective on the environment *from here* (e.g., the increasing amount of space that the table occupies in one's visual field the closer one gets to it).

In the case of CMIG, one may worry that because the image generated and maintained is decoupled from the causal source of its spatial dimensions, there fails to be invariant information that acts as a complement to the proposed variant information. This worry may be avoided when taking a few facts about imagery into account. As we have seen above, when imagining a particular object, one's saccadic eye patterns are similar to those which would occur if one were actually perceiving that kind of object (Thomas, 1999; Fourtassi et al., 2018). This saccadic re-enacting of the object spatial relations brings with it a multiplex of visually registered stimuli. I would like to suggest that this stimuli, variant information, acts as afferent feedback for helping to guide the visual system in ways that efferently maintain (or systematically alter) the imager's *perspective* on that which was sampled.[135] In the case of CMIG, variant information does complement invariant information, but the latter need not be something that is currently coupled to for the former to continue to guide saccadic re-enactment. Any non-homogenous stimuli will serve the purpose of providing variant information (i.e., feedback) as long as it

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[135] One might object here that it is possible for one to generate a visual image in complete darkness where no such variant information is available and one's eyes nonetheless saccade in ways that reflect the spatial relations of the imagined object that was previously perceived. Assuming that one is in a condition of complete darkness —something that is rarely the case in non-experimental environments—in order for this objection to hold it must be shown that both saccades and image maintenance in the two conditions of complete darkness and in typical viewing conditions are identical. This is an open empirical question. More importantly, in the case of CMIG, typical perceptual lighting conditions are necessary.

is in the particular range that does not degrade imagery. What qualifies such stimuli as variant information *is how it is used to maintain one's perspective on invariant structure in the environment*.

For example, in the disk game, by coupling to invariant spatial structure of a particular disk, one simultaneously couples to the variant, perspectival, information that accompanies it. After the disk is sampled, one's visual system decouples from it and yet remains coupled to the changing light stimulus encountered. The visual system, by using differences in light stimulus as feedback to continue the perspective-driven saccadic pattern, is able to maintain a phenomenal perspective on the spatial dimensions of the disk. This is not to say that one cannot alter one's perspective, something that is clearly the case in mental rotation tasks. The point is that extracting variant information from the environment is a process of using stimuli as feedback to drive saccades (and the visual system generally) in order to re-enact a perspective on invariant structure that is absent. This re-enactment process is not just driven by inner dynamics but guided by variant information in the environment.[136]

Visual variant information is generated by the interaction of saccadic patterns and differential light stimulus. Changes in impinging stimulus act as feedback—a kind of 'scaffold'—to control (confirm and correct) saccadic patterns.[137] It is here that stimulus-sensitivity comes into play. Some stimuli which the visual system attempts to couple to in re-enacting perspectival structure can be of magnitudes too intense (or not intense enough) to act as feedback and thus corrupt the on-going saccadic pattern. Whilst the perceiver is simultaneously moving her sensory surfaces through the environment, high luminance stimulus that is encountered

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[136] I will assume that other features of imagery like colour piggyback on re-enacting perspective. (See Bompas & O'Regan, 2005).

[137] The generation of imagery without sampling of perceived dimensions may similarly involve the engendering of saccadic eye patterns as a result prior perceptual system biasing. These patterns are sustained (i.e., confirmed and corrected) by the generation of and coupling to variant information.

marks out the locations which saccades should avoid. Adaptive saccadic adjustments are made whilst the overall saccadic pattern is sustained.

Although variant and invariant information are complementary, it is possible for a cognizer to remain coupled to the former whilst decoupling from the latter. In the case of CMIG, one may actively couple to stimuli in the environment which allow for imagery maintenance *from here*, whilst decoupling from the invariant information that is causally dependent upon the particular object sampled. To maintain an image in CMIG is to (at least in part) adjust to the stimuli encountered in ways that allow for a lasting perspective on that which was sampled. Coupling to variant information in CMIG involves the tacit guiding of the perceptual system so as remain receptive to the range of stimuli that do not result in the loss of one's perspective. It is telling that the phenomenology of mental imagery—with respect to objects—is *essentially* perspectival.[138] The difficultly (or more likely, impossibility) of taking more than one perspective at a time on a generated image, if this account is correct, is more to do with the fact that it is not possible to re-enact multiple perspectives simultaneously with saccades.

Although this kind of coupling does not take environment-specifying information as one of its *relata*, it is nonetheless a form of coupling to perspective-specifying, behaviour guiding variant information.[139] The claim that a perceptual system may be decoupled from invariants and nonetheless operate in non-(strictly)perceptual cognition is supported by Gibson when he writes:

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[138] I have qualified this statement to apply to objects given the possibility of generating an image that consists of nothing other than uniform colour or (i.e., a ganzfeld). Although there is no perspective involved in such a ganzfeld, generated images of objects seem to be perspectival through and through.

[139] This kind of divergence of coupling to variant information from coupling to invariant information may be exemplified in the following example: whilst looking out the window of a high-speed train and staring steadily at a fixed area in the foreground, one is strongly decoupled from much of the invariant information specifying individual objects outside due to their size (say, a piece of fruit hanging from a tree) and the speed travelled. Despite this, one can couple to the present variant information specifying one's perspective; a perspective *from here* that phenomenologically encompasses one's moving at a certain velocity in relation to a static *out there*.

> "…a perceptual system that has become sensitised to certain invariants (information) and can extract them from the stimulus flux can also operate without the constraint of the stimulus flux" (Gibson 1979, p. 256).

In line with Gibson's claim, the account being developed here proposes that subsequent to being sensitised to invariant structure (i.e., sampling), a perceptual system can couple to behaviour guiding variant information sans the invariant structure of the object sampled. Variant information is necessary for perspectival re-enactment (e.g., saccadic guidance and pupilar response) in CMIG.[140] It is this coupling to variant information that I shall call *variant coupling*. It may be contrasted to *invariant coupling* (i.e., coupling to invariant information).

5.5 Sketching a Taxonomy

Taking the proposed account of CMIG into consideration, I would now like to sketch a taxonomy of online/offline cognition which, going beyond the limited specification criteria of stimulus-present and stimulus-absent, includes weak coupling and stimulus sensitivity. The previous sections have provided reasons to think that such a taxonomy may accurately represent the underlying relations and features of CMIG. Before proceeding with this sketch, however, a few remarks are necessary. To remind the reader, the continuum thesis, beginning from the evolutionary assumption that imagery capacities developed from simpler perceptual capacities, states that perception and imagery share some of the same

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[140] Another way of interpreting Gibson here is to view imagery (or memory) as emerging from the re-enactment of the kinds of activities which were carried out when a perceiver was actually coupled to invariant information in the absence of such information (Kiverstein & Rietveld, 2018). The account developed in this paper goes further than this analysis, linking re-enactment to feedback provided by coupling with variant information.

underlying processing. Is there a reason to believe that variant coupling names a kind of processing that is a shared feature of perception and the imagery involved in CMIG? And if so, is variant coupling a more general feature of both online and offline cognitive phenomena?

In response to the first question, the analysis of CMIG provided above suggests that endorsing the ecological claim that both variant and invariant information pick-up is involved in perception gives reason to think that weak coupling is involved in both perception and CMIG. In response to the latter, more general question, the claim that weak coupling is involved in all offline phenomena may certainly be challenged. The onus, however, falls on one who denies that there are stimulus-insensitive processes to demonstrate—pace our intuitions—that all offline cognitive phenomena are coupled to variant information. Any argument in favour or against stimulus-insensitive phenomena would take us too far afield, given the aim and limited scope of this paper. However, in assuming that *some* cognitive phenomena are stimulus-insensitive the following sketch of an offline/online taxonomy that does justice to CMIG begins to take shape. (see Figure 12 and Table 2).

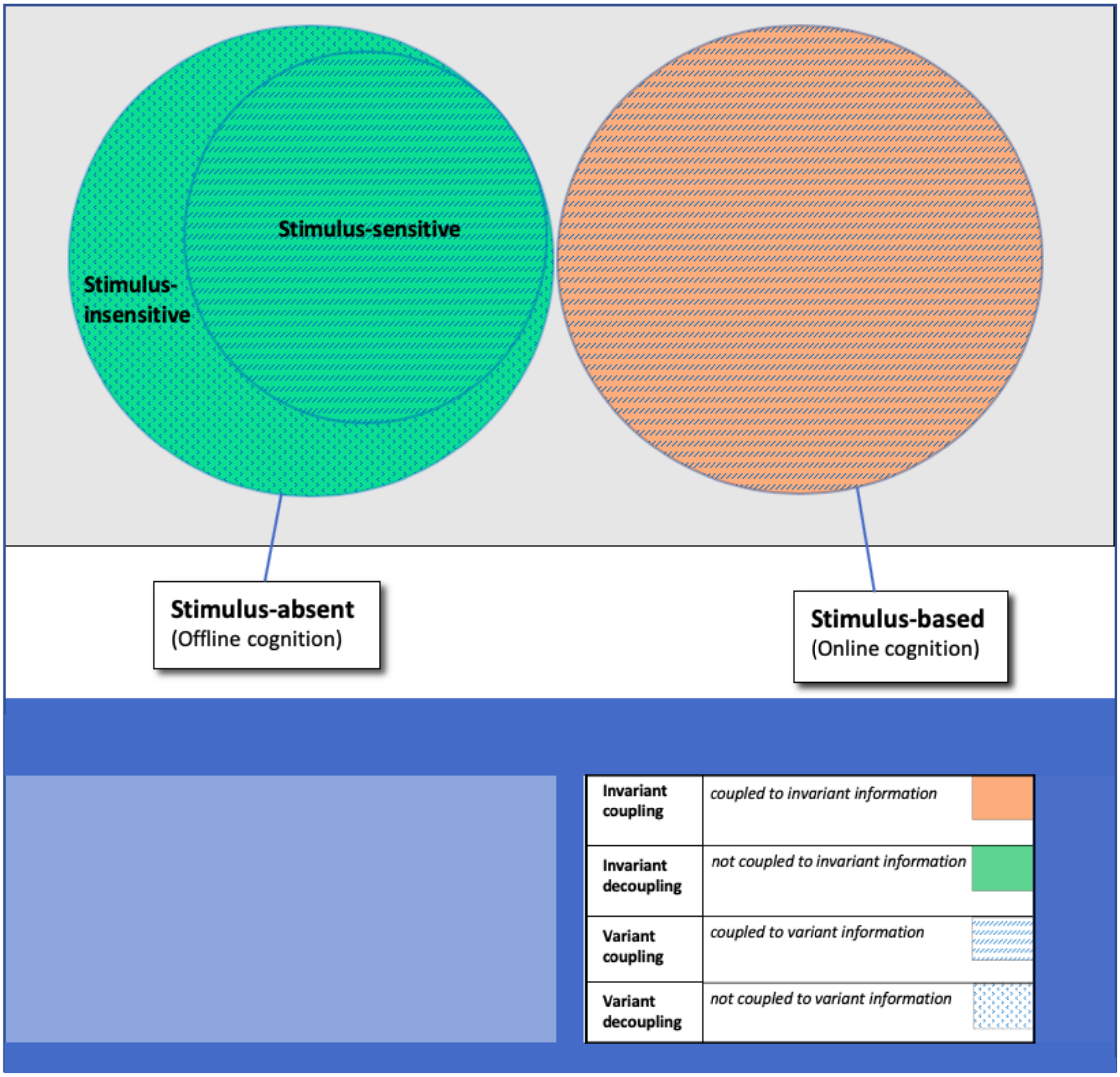
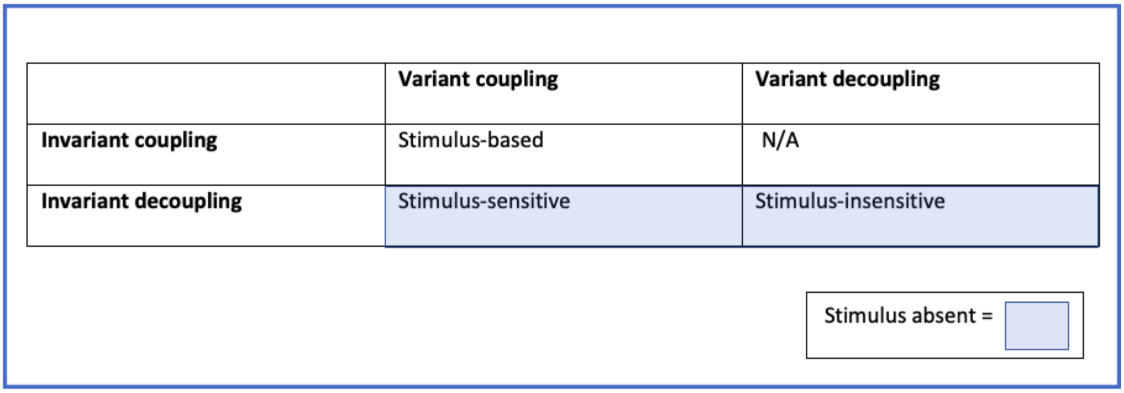


Figure 12

Coupling in CMIG: assuming that there are offline cognitive phenomena that are stimulus-insensitive (i.e., imagery, the generation and maintenance of which is immune to environmental stimulus encountered and thus do not elicit adaptive control responses), stimulus-sensitive and stimulus-insensitive are both ways of being stimulus-absent (offline) cognition. A stimulus-sensitive process is distinguished from stimulus-insensitive process in that it is both decoupled from invariant information but coupled to variant information, whereas a stimulus-insensitive process is decoupled from both invariant information and decoupled from variant information. Stimulus-based perception is coupled to invariant information, however, like stimulus-sensitive imagery, involves also variant coupling. CMIG is a stimulus-absent process of the stimulus-sensitive type (i.e., invariant decoupling and variant coupling) which occurs concurrently with stimulus-based perception. This allows for variant information that is generated in stimulus-based perception to act as a feedback in stimulus absent imagery maintenance and hence to be coupled to inner-dynamics.

In CMIG, mental images are decoupled from invariant information yet remain coupled to variant information in the environment. In contrast, online perception involves both invariant and variant coupling. Importantly, being stimulus-sensitive (or possibly stimulus-insensitive) is a way of being stimulus-absent. In other words, stimulus-sensitivity is a determinate of determinable stimulus-absent. On the other hand, there is no further determinate of stimulus-based cognition.



	Variant coupling	**Variant decoupling**
Invariant coupling	Stimulus-based	N/A
Invariant decoupling	Stimulus-sensitive	Stimulus-insensitive

Stimulus absent = 🟦

Table 2: Implication relations. Stimulus-based implies being both variant and invariant coupling. Stimulus-sensitive implies variant coupling and invariant decoupling, and granting the possibility of stimulus-insensitive phenomena, stimulus-insensitivity implies being variant decoupling and invariant decoupling. Since stimulus-based has no determinate, there is nothing that is implied by being both decoupled to variant information and coupled to invariant information. This suggests that being coupled to invariant information is dependent upon variant coupling.

5.6 Conclusion

Both the proposed action-based account of CMIG and the taxonomical sketch on offer here may only do the work that I suggest that they may in fact do if the one is willing to concede that coupling is not restricted to the strong variety involving Gibsonian invariant information. However, the fact that variant information has been previously given a valid place within ecological analysis should make the notion of variant coupling more attractive to any theorist who is already sympathetic to the ecological framework. If the argument that I have presented above is correct, CMIG is both stimulus-absent and stimulus-sensitive: the imagery in CMIG is decoupled from the sampled invariant structure and yet remains coupled to the range of flowing variant information that enables the behavioural responses for maintenance of a perspective on that which was sampled. As such, the internal dynamics during CMIG are not detached from the environment but subtly coupled to it as the environment provides the feedback required for a stimulus-absent perspective.

CMIG is an interesting phenomenon because it calls into question the view that all mental imagery is an offline and decoupled process. The kind of variant coupling that I have suggested underwrites CMIG is a natural extension of the ecological construct of environmental information. This deployment of the ecological framework to the analysis of CMIG has been shown to yield a novel taxonomy of online/offline cognition which goes beyond stimulus-presence and stimulus-absence. In virtue of the place this taxonomy allows stimulus sensitivity, it is able to do justice to CMIG's status as an offline and coupled phenomenon. Despite any hard to shake reluctance that one may have in accepting the accuracy of this taxonomic sketch, it may be nonetheless reasonably concluded from the case study of CMIG provided that any online/offline distinction which fails to allow for stimulus sensitive cognitive processes is inadequate. CMIG demonstrates that the online/offline bifurcation fails to be as clear-cut as it seems.

What ramifications might this analysis of CMIG and variant coupling have for the general project of articulating an ecologically informed enactivism. Assuming that some accounts of ecological enactivism attempt to account for all basic cognition with the notion of inner and environmental dynamical coupling (Kiverstein &

Rietveld, 2018; Rietveld & Kiverstein, 2014; Bruineberg et al. 2016,2018), one reason that the ecologically informed enactivist might be moved to adopt the notion of variant coupling is the following thought: even in those cases in which cognizers fail to be coupled to invariant information in their environment, they may be thought to be continuously—to varying degrees—coupled to variant information in it. For the purposes of sketching an online/offline taxonomy that can account for CMIG, it was assumed that there are stimulus-insensitive phenomena. Going against this assumption, it may be asked *whether there is ever a situation in which a cognizer is completely isolated from impinging environmental stimuli?*

Answering this question negatively might suggest that all mental imagery could be stimulus-sensitive to varying degrees. This would allow the 'eco-enactivist' to work backwards from those putative cases of stimulus-absent cognition to considerations about the causal effect of variant environmental information upon various types of non-comparative mental imagery generation or offline cognition more generally. Whether or not all mental imagery is in fact stimulus-sensitive is an empirical question which conceptual analysis alone cannot decide. Even in the case that there are forms of offline cognition which are stimulus-insensitive, the concepts of stimulus-sensitivity may nonetheless provide a means for more carefully distinguishing those phenomena that are coupled in those distinct ways elaborated in this paper from those that fail to involve coupling *tout court*.

Conclusions

When attempting to understand strong continuity of life and mind, two questions become the focus of the investigation: *what* are the common organizational principles and properties are shared by living processes and cognitive processes? And *how* are the principles and fundamental to life enriched so as to result in cognitive processes? In this thesis three anticipatory cognitive frameworks have been deployed to investigate these questions. It was also intimated that taking up the strong continuity thesis from the perspective of FEF, PP, and EP would expose more about the explanatory scope of each of these frameworks, their relations, and that they may be used together to answer some puzzling questions regarding biological cognition. The remainder of this thesis will make explicit what was gleaned from each framework (independently and/or jointly) concerning possible continuity principles and enrichment properties.

The Free Energy Framework and Strong Continuity

In chapter 1, it was argued that FEF may be seen as a kind of biogenic framework which starts by viewing cognition as a biological process that is grounded in free-energy minimization. Free-energy minimization allows a living system to actively provide evidence for itself as a model of the kind of environment that it should encounter, bringing about the very bodily and environmental conditions required for it to remain alive. Thus, at the heart of FEF lies an imperative that bridges life and cognition; the free energy principle states that any thermodynamically open system that appears to resist the tendency of entropic decay is one that minimizes variational free energy. The free energy principle, which was put into use in chapters 2 and 3, provides a clear example of the kind of fundamental organizational principle that the strong continuity thesis posits as common to life and mind.

We saw however in chapter 3 that free-energy minimization in biological systems, although necessary for biological cognition, is not sufficient for cognition. Adaptive active inference as opposed to mere active inference is required (Kirchhoff & Kiverstein 2019a, 2019b). That is, being a cognizer demands that a living system engage in a high degree of autonomous free-energy minimization; it must be the primary source of its self-evidencing processes (i.e., active inference and perceptual inference). This constraint on cognition, besides enabling FEF to avoid the charge of being overly permissive that Adams (2018) foists against biogenic approaches (chapter 1), suggests one way in which to answer the enrichment question posed above: living processes rise to the status of cognitive processes when living Markov-blanketed systems have the capacity for a high degree of autonomous self-evidencing. The proposed kind of enrichment, it was argued in chapter 3, allows us to answer the following question: why are mitochondria not cognizers despite their being free- energy minimizing living systems? The answer we saw was that the free-energy minimization that a mitochondrion engages in is too dependent upon the activities of the larger cellular matrix within which it is situated for it to qualify as a highly autonomous self-evidencing system.[141]

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[141] Interestingly, mitochondria may have been at one point in their history—prior to their being endosymbionts—autonomous enough to qualify as minimal cognizers. I conjecture that if the picture of complexity matching is correct, it may have been the decrease in environmental uncertainty for mitochondria brought about by their entering to the mitochondrion-cell symbiotic association that resulted in a decrease in their autonomy. This is an instance in which traits underwriting cognition may have been gradually selected against.

Moreover, taking this approach to enrichment provides the FEF theorist with a principled manner of identifying biological cognizers that may not fit with our intuitive folk-psychological conceptions of what cognizers are. This itself has consequences for understanding possible ways in which complex cognitive mechanisms have evolved from those of lesser complexity. A case was made for the notion of a symbiotic mind based upon the idea that some symbiotic associations (e.g., Vibrio-squid symbiosis) engage in autonomous self-evidencing at the level of the symbiotic unit. This kind of striking result is important because it offers cognitive scientists and biologists one manner of understanding a possible transition in cognition: from multi-organismal cooperative action to the purposive intelligent behaviour of a multicellular individual. FEF, by providing both a common organizational principle of life and mind (i.e., the free-energy principle) and an answer as to how living processes have been enriched so as to result in cognitive processes (i.e., a high degree of autonomous self-evidencing) not only sheds light upon the strong life-mind continuity thesis, but in doing so provides a some helpful concepts that may be used to identify cognition in its various forms.

Predictive Processing and Strong Continuity

Throughout this thesis action-oriented PP (Clark, 2016a) has been deployed. This variant of PP emphasizes that the prediction driven dynamics core to PP are not aimed at constructing accurate generative models or ‘true’ predictions but at providing agents with a satisficing means to adaptively respond to the changing dynamics of the environment. As such, the link between life and mind implicit in PP is that cognition is fundamentally in the service of guiding world engaging adaptive behaviour; something itself which may be interpreted as an expression of the environmental complexity thesis (ECT) that was introduced in chapter 0.

What does PP suggest regarding common underlying organizational principles of life and mind? We saw in chapter 2 that PP may be subsumed under FEF. Given that prediction error, under simplifying mathematical assumptions, is equivalent to the quantity of free energy, minimizing free-energy is the same as minimizing prediction error. When nesting PP in FEF, the free-energy principle maintains its status as a common organizational principle of life and mind. This being said, even when viewing PP as nested within FEF, it should be remembered that free-energy minimization (and hence prediction error minimization) is not sufficient for cognition but something else is required: autonomous self-evidencing. Living systems become more enriched so as to become cognitive systems with an increased ability to actively regulate their own sensory and behavioural traffic with their environments (i.e., adaptive active inference), providing sensory evidence for the generative models they instantiate.

Similarly, prediction error minimization may occur in PP in various domains that are determined by the nature of the predictions (i.e., exteroceptive predictions, proprioceptive predictions and interoceptive predictions). Interceptive prediction errors, like exteroceptive and proprioceptive errors, may be resolved by active inference which enlists autonomic reflexes and some biochemical processes (as opposed to engaging the motor system or motor reflexes (Seth & Friston 2016). Although this process of altering physiological variables in order to return to homeostatic equilibrium reduces interoceptive prediction error, minimizing prediction error in this manner does not by itself qualify as cognition according to PP (neither in FEF nested PP nor in PP as a standalone framework). Why? Although reducing interoceptive prediction error is often interwoven with reduction of exteroceptive and/or proprioceptive prediction error reduction, these reflex driven autonomic system responses are too hardwired and inflexible to qualify as cognitively driven intelligent behaviour. In other words, interoceptive prediction error minimization by itself fails to involve what in chapter 1 was called “weak intentionality” (i.e., phenotype-relative “aboutness” of internal dynamics directed at target objects/gradients that causally underpin adaptive behaviour). Interoceptive prediction error minimization by itself is a kind of closed loop feedback control that allows for the maintenance of homeostasis via local autonomic response. As we saw in chapter 1, weak intentionality requires more than this. It demands the enlisting of sensorimotor and/or biochemical behaviour strategies—along the lines of allostatic control—that by investing homeostatic resources now enable the organism to maintain its long-term homeostasis and hence provide sensory self-evidence for its own existence. Such evidence is by its very nature meaningful (e.g., unlike for a human, garnering sensory evidence of being submerged in water over a long period of time for a fish means ‘I will exist’) and such strategies are imbued with weak intentionality.

What does PP offer that FEF does not in terms of telling us about the strong continuity of life and mind? Since PP places structural constraints on the kinds of mechanisms that it views as central to cognition, it offers a principled manner of understanding how such mechanisms may be structurally implemented and how certain mechanisms that serve more complex functions (e.g., attention, context sensitive behaviour, etc.) may require increased structural complexity. As it was shown in chapter 2, although PP is typically applied to humans (or more generally animals with neuronal substrates), this need not be the case. In arguing for the plant predictive processing hypothesis (Calvo & Friston, 2017), we saw in chapter 2 that a slew of evidence has been gleaned in support of the claim that plants engage in anticipatory and purposive perception-action. In light of the kind of enrichment property that this thesis has uncovered, we may now understand this claim in terms of adaptive active inference: plants autonomously harvest evidence for their own existence by purposively interacting with their environments so as to bring about the conditions in which they can continue to survive and thrive.

To this, and relevant to the question of enrichment, we saw that plants have PP compatible electrophysiological profiles and a physical structure that could implement hierarchical bidirectional message passing. Possessing a physical organization that could allow for hierarchical bidirectional message passing is a structural constraint on PP agents (and hence on cognitive processes). As it was argued in chapter 2, *pace* traditional PP accounts, this structural constraint can be satisfied in non-neuronal systems. However, to advance beyond the kind of minimal perceptual capacities (i.e., perception of global chemical concentration gradient increases and/or decreases and their affordances) that plants and perhaps other non-neuronal living systems possess to maximal perceptual capacities (i.e., the perception of objects and their affordances) may require a kind of physical structure on the part of the predictive agent that supports predictions (and models) with an increased temporal depth. Nervous systems seem to be one likely candidate for such a structure. This thesis suggests the following: living processes are enriched so as to support cognitive processes both in terms of (a) an increased degree of autonomy and (b) an increased structural complexity that allows for generative models with more and more temporal depth to take root. The structural constraints that PP places upon the kinds of cognitive architectures that can get into the hierarchical bidirectional message passing game sheds light upon the kind of enrichment of living processes expressed by (b). Put into the terminology introduced in chapter 1, moving from weak intentionality to strong intentionality across the continuum of intentionality involves (at least) possessing physical structures and organization that can implement the kind of integrated and fast message passing that temporally deep models require. As living processes are further structurally enriched, cognitive processes allow for anticipation of action outcomes further into the future based upon ontogenetically learnt evidence that reaches further into past experience.

One such sophisticated cognitive capacity that the kind of enriched structure of human nervous systems allows was given treatment in chapter 4. We saw that perception of affordances is modulated by historical context. Historical context sensitivity (HCS) may be elegantly accounted for within the PP framework with the mechanism of precision weighting. However, the form of precision weighting constitutive of working memory in HCS may come apart from the other forms of precision weighting and core mechanisms of PP. For example, the kind of PP that occurs in non-neuronal organisms might involve precision weighting (i.e., decreased precision on proprioceptive error that allows for behaviour to take place), but because their physical structure places limits upon connectivity, integration, or other factors, the kind of precision weighting that results in HCS (i.e., precision as product of working memory) does not arise.

HCS seems to demand a shift towards the use of updated prior ‘beliefs’ to drive behavioural response. That this shift can occur in response to varying contexts not only presupposes that certain mechanisms are in place but that responding to certain contexts is something that is adaptive for the agent. It stands to reason then that the limits of direct perception are important for a framework such as action-oriented PP because such limits may very well demarcate where distinct (yet interacting) kinds of mechanisms and processes get a foothold relative to the kinds of increasingly complex niches that predictive agents have evolved with. As suggested in chapter 4, the capacity to use precision weighting to increase the impact of priors on object perception over time may very well represent a kind of cognitive transition marker separating biological systems with and without working memory.[142] This transition marker defines a difference in the degree and manner in which environmental information is used relative to the degree and manner in which precision weighted prior ‘belief’ drives adaptive behaviour.

To sum up: whether nested within FEF or used alone, action-oriented PP suggests a form of structural enrichment that living processes must have in order to qualify as cognitive processes. That is, if a living system fails to have the kind of physical structure that would at least allow it to instantiate a two layer generative model (i.e., a hierarchical organization allowing the passing of at least a top-down prediction signal and a bottom up sensory/ error signal) it would fail to be the kind

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[142] Just how the capacity to use precision weighting this way is related to the kind of “unlimited associative learning” that Ginsburg & Jablonka (2019) identify as a transition marker for minimal conscious systems is an interesting question that I hope to pursue in future research.

of system that could in theory be a cognitive system. This, however, is not to suggest that there are living systems which indeed fail to have such a structure. When PP is subsumed within FEF, the fact that all living cognitive systems must obey the free energy principle suggests not only that they minimize prediction error but that they do so by way of instantiated hierarchical generative models that elicit the kind of bidirectional message passing that is core to PP. If this is the case, PP's structural constraint provides a kind of *distance measure*: by being subject to further structural enrichment over evolutionary timescales, living systems which are already hierarchically structured develop the ability to engage with temporally distal future events conditioned upon both current and past sensory evidence; this is a movement from weak intentionality to a form of strong(er) intentionality.

Such a structural distance measure does not conflict with plant predictive processing (or bacterium predictive processing for that matter!) but rather places it in a larger ecological context since the capacity to predict the outcomes of their current behaviour over temporally slow timescales (e.g., weeks, months, and years) is not something that is required of plants (or simpler organisms) for them to cope with the kinds of environmental complexity that they tend to encounter in their eco-niches; the physical structure of plants and simple organisms is complex enough to harness the statistical structure that they must anticipate and respond to at the faster timescales which they occupy. More complexity in a niche drives further complexity (structurally and/or functionally) in the organism which may result in further alteration of the niche, making it even more complex over time. PP, by emphasizing hierarchical structure and the connection that such structure has to temporally thick predictions and deep models, offers the strong life-mind continuity thesis a description of one manner in which the enrichment of already complex living and cognizing systems become further adapted to increasingly complex environments. PP offers a computational manner of understanding what throughout the current thesis has been called "complexity matching". This brings us to the third framework which this thesis has deployed in order to glean insights into strong life-mind continuity.

Ecological Psychology and Strong Continuity

In this thesis ecology psychology (EP) has played a principal role in providing a selection of conceptual tools (i.e., affordances, environmental information exploitation, perceptual medium and organism-environment mutuality) that have been deployed in accounting for various cognitive phenomena. As originally proposed by Gibson (1966, 1979), this ecological toolkit has been used to account for active perception in a manner that avoided recourse to top-down processing and modulation by memory states (chapter 4). In this thesis, rather than being constrained by EP's notion of direct perception, the concepts of affordances, environmental information exploitation, and organism-environment mutuality have been adopted for use from within the frameworks of FEF and PP in an effort to identify and understand different kinds of frugal cognitive strategies and mechanisms that might underpin the adaptive behaviour of simple and non-neuronal organisms, strategies and mechanisms which have been conserved in complex neuronal organisms.[143] Affordances and ecological information pick-up provide a manner of thinking about the 'bare bones' basis for anticipatory cognitive processes from which more elaborate cognitive mechanisms and prediction driven strategies may have evolved.

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[143] The idea having been that the theoretical apparatus that direct accounts of perception deploy may be used external to the theory of direct perception; a framework which uses the notion of environmental information exploitation in the analysis of certain psychological phenomena need not itself be committed to the rejection of inferences or memory states as constituent parts of perceptual processes. For this reason, although a direct perception theory like EP cannot be expanded by the mechanisms of PP, PP can be expanded by the theoretical apparatus underwriting ecological direct perception

One thing that is presupposed in deploying ecological conceptual apparatus is that perception (and cognition more generally) is an environmentally coupled sensorimotor activity that involves extracting information for perception (and action) from the environment. This kind of coupling, we saw in chapter 5, can possibly go further than accounting for online perception, providing a plausible manner of explicating some kinds of mental imagery generation. With this in mind, one way of answering the question as to how the properties and principles constitutive of living processes have been enriched so as to result in cognitive processes may be brought out by considering the place of *sensorimotor behaviour* as a condition for cognitive processes. Taking a broad conception of sensorimotor behaviour that is (minimally) driven by weak intentionality (chapter 1) and includes not only motor control but directed growth that occurs in plants (chapter 2) and some *controlled* biochemical responses (chapter 1 and chapter 3), one might argue as follows: assume that the capacity to engage in sensorimotor behaviour is essential for EP's conceptual apparatus to be deployed in cognitive explanation, and that not all living systems have the capacity to engage in sensorimotor behaviour; if EP's apparatus feature into the best explanation of some minimal (i.e., basic) forms of cognition which happen to be the basis for all non-basic forms of cognition, then sensorimotor behaviour would seem to be a requirement for both basic and non-basic cognition.

Sensorimotor behaviour follows from the kind of weak intentionality that in chapter 1 was argued is sufficient for cognition. If there are in fact organisms which fail the capacity for weak intentionality driven sensorimotor behaviour (so broadly conceived), then these are the kinds of organisms which would lack cognition despite their being able to minimize free-energy and keep themselves alive via interoceptive predictions and homeostatic regulation.[144] For example, simple

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[144] How would controlled biochemical processes qualify here as adaptive free-energy minimizing behaviour rather than reduction of interoceptive prediction error? Consider the hypothetical case of a particular snake that could volitionally make its venom more or less potent depending upon how large or small it perceives its prey to be. This is a controlled biochemical process that I think

organisms which fail the capacity to use current environmental sensory cues to anticipatorily guide metabolically expensive behaviour in order to avoid irrecoverable deviation from homeostatic norms may be one example of organisms that lack sensorimotor behavioural capacities; such simple organisms would largely be slaves to the dynamics of their homogeneous milieus. Short-term physiological and/or reflex-like recovery from environmentally caused homeostatic deviation would be the extent of their activity.

When locating sensorimotor behaviour within the context of affordance perception, it becomes evident that one manner in which life may have been enriched so as to support cognition is by the addition of sensorimotor mechanisms and processes that allow living systems to purposively move around to actively reveal affordances in the array. In chapter 2 we saw that plant predictive processing gives us reason to believe that plants, like neuronal organisms, anticipatorily perceive and adaptively behave in ways that keep them far from thermodynamic equilibrium. Importantly, if the account of minimal-perception that was introduced in chapter 2 is correct, plants (and possibly other non-neuronal organisms) in detecting the invariant structure of chemical concentration gradients within their perceptual medium, anticipatorily perceive constancies. Relative to the plants as perceivers, these constancies are none other than affordances (e.g., a nitrate gradient increase affords sustenance). If follows from the fact that affordances are relational properties (i.e., they are properties of the environment relative to the perceiving-acting organism), and because they are construed in EP as the primary things perceived, that perception-action is fundamentally in the game of serving an organism's adaptive response to its environment given its needs. That is, the very notion of affordances suggests that cognition has the function to keep organisms appropriately coping with (i.e., staying alive in) their niche, thus reiterating the environmental complexity thesis (ECT).

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has all the makings of a purposeful behaviour despite the fact that it does not involve the snake's initiating a *motor control* that changes its sensorily observable relation to the environment.

Staying alive—at a certain level of organismic complexity—from an ecological perspective may roughly be conceived as perceiving and exploiting those affordances that would allow a living system to continue perceiving and exploiting affordances in its niche. Staying alive in more complex environments—and at a higher level of organismic complexity—may require not only perceiving affordances but creating them, thus sculpting the very environment that one is adaptively responding to. Affordances whether available or created are future-oriented relations. They provide a concrete manner of understanding how anticipatory life has become enriched to arrive at anticipatory cognition: while not all living systems may have the capacity to perceive affordances and engage in the sensorimotor behaviour required to actualize them, this thesis has provided some reasons to believe that all systems that are bio-cognizers possess this capacity. Biological cognitive systems are those that have (amongst other things) become tuned to the abundance of rich environmental information available for perception-action, reflecting the ongoing organism-environment mutuality that is central to ecological explanation.

Returning to active adaptation

We started this thesis with a few initial characterizations of life and cognition. It was suggested that both life and mind might share a common characteristic of serving the active adaptation of the living system to the complexity of the environment. That is, it was suggested that both life and cognition are endogenously driven processes in virtue of which biological systems tend to preserve their organization by adapting to encountered environmental fluctuations. In using FEF, PP and EP to explore the various forms that cognition takes along the continuum of intentionality and given what has been proposed about how cognition arises out of free-energy minimization (prediction error minimization) that is enriched through increased autonomous self-evidencing, the chapters of this thesis have gone a long way in supporting this initial suggestion. For instance, recall that weak intentionality is essentially a normative property of living systems, such that any system's behaviour that is guided by weak intentionality is measured against states of the world (and states of the organism) that 'should' be observed given the kind of organism that the living system is (i.e., its phenotype). This kind of normativity is something that is endogenous to the system in question, arising from the processes and mechanisms that underwrite the system's microscale (physiological-level) activity and which are constrained by the system's macroscale (psychological-level) behaviour. As such, weak intentionality is a description of the active and endogenously driven aspects of living processes that span biological and psychological domains, and which help to solidify active adaptation as a common property of life and mind.

We are now, however, in a position to sharpen and enrich this notion of active adaptation given what we have gleaned from investigating strong continuity from the perspectives of FEF, PP and EP.

When using FEF, PP and aspects of EP jointly, the following may be concluded: the free energy principle is a common organizational principle that underlies both life and mind that allows organisms to deal with environmental complexity. Moreover FEF, PP, and EP as combined in this thesis reveal at least four manners in which life has been enriched to arrive at cognition. These are:

E1. An increase in the degree of autonomous self-evidencing
E2. An increase in temporal depth of model/ predictions
E3. The introduction of the capacity for sensorimotor behaviour
E4. An increased sensitivity to environmental information for affordance perception

Increasing anticipation, increasing temporal depth, and increasing model complexity

One common characteristic of PP, FEF and EP which was a central motivation for choosing these frameworks to investigate strong life mind continuity was the fact that they all view cognition as an anticipatory process. Anticipation in FEF and PP underpins the very expectation-driven processes that are constitutive of adaptive active inference. While in EP, the place of anticipation in cognition (active perception) is intrinsic to the notion of affordances.

E2, I would like to suggest, is key to understanding how increased hierarchical complexity of generative models and predictions in PP and FEF results in increased anticipatory capacities. As such the latter kind of increase may be seen as a functional description of E2. Temporal-depth (sometimes referred to as temporal thickness) of a model is generally seen as the capacity for generating long timescale predictions of the kind of sensory feedback that would arise were a protracted sequence of actions initiated to bring spatially (or temporally) distal environmental objects into the purview of immediate action (Kiebel, Daunizeau & Friston, 2008). Assuming that temporal depth is a universal feature of generative models in biological self-maintaining systems (Kirchhoff, Parr, Palacios, Friston & Kiverstein, 2018), models may vary both in degrees of depth deployed from problem space to problem space and degrees of depth available from organism to organism; not every hierarchical level of a generative model must be deployed in order to resolve prediction error in every problem space across the board. Similarly, not every environmental niche demands the same degree of future oriented deep-model driven behaviour; a little temporal depth in less complex environments may go a long way! As anticipatory capacities increase along with the temporal depth of models, the capacity to reduce variational free-energy is augmented with the capacity to minimize *expected free energy* (i.e., the free-energy that arises from the disparity between preferred sensory outcomes of action and the actual sensory outcomes of actions).

It is when attempting to answer the question “what are the conditions under which the lower end of the model-depth spectrum are deployed?” that the distinction between the environmental medium and the environmental layout (i.e., structure) beyond the medium becomes suggestive of an interesting and useful partition: *deep functioning levels* are those at which generative models function to predict the sensory feedback that would occur were actions upon the structure beyond the medium initiated; *shallow functioning levels* are those at which generative models function to predict the kind of sensory feedback that would occur were actions upon (or with respect to) the perceptual medium initiated. This partition is captures two distinct, yet causally interacting, environmental realms that generative models of varying depth allow error minimizing interaction with: the environmental layout beyond the medium (i.e., objects with certain degree of permanence such as mugs, hills, people, etc.), and higher-order invariant structures in the perceptual medium (e.g., chemical gradients, mechanical gradients, etc.).[145] This model-depth distinction may be also recast in terms of the minimal vs 'maximal' perception distinction that was proposed in chapter 2. Models functioning at the deep level distil environmental information for the perception of affordances that the environmental layout offers. Models functioning at the shallow level, on the other hand, distil environmental information for the perception of affordances that the higher-order structure of the medium itself offers. One example of this latter kind of affordance is an increasing hydrogen sulfide gradient. Smelling the increasing gas gradient itself is sufficient for guiding behaviour away from the direction of further increase in concentration. An agent, in such a case, is not avoiding the source *per se*, but avoiding the increasing level of putrid gas in the air medium.

To be sure, generative models may function (often simultaneously) at both levels. What determines the degree to which a model functions at the shallow or deep level is the nature of source of possible prediction error that must be minimized. As the source of possible prediction error grows in complexity, so does the need for models to function at deep levels. Thus, one manner in which living processes have been enriched, as suggested by E2 above, may be unpacked in terms of increased anticipatory processes, which itself when using FEF or an FEF nested PP suggests the kind of relationships between environmental complexity and organismic (model) complexity that are illustrated in Figure 13.

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[145] Although, in this exposition I have focused on the external milieu, the environmental realms which the partition exposes may be equally understood in terms of the inner environments. With respect to interoception, the more permanent environmental realm is that of expected bodily states as defined by an organism's phenotype (i.e., a temperature of approximately 37.0 degrees for a human). One example of an inner medium in such cases may be blood which carries chemical gradient information.

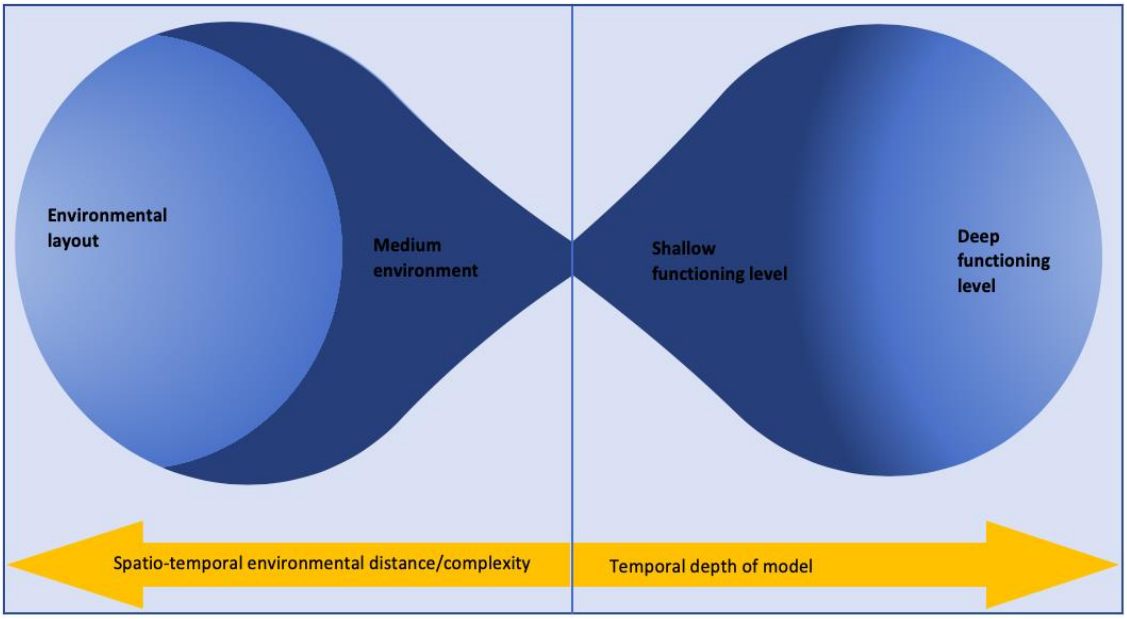

Figure 13

Relations between environment and model: In the environment there are two distinct realms labelled medium environment and environmental layout. These lay along a dimension of increasing complexity. On the agent side of the divide, the model is partitioned in to two distinct levels corresponding to the two environmental realms. The shallow functioning level and deep functioning levels respectively lay along a dimension of increasing model depth. The distinction between the shallow and deep functioning levels of the model are fuzzy, shading into one another.

The manner of temporal-depth specification on offer, by serving to emphasize that environmental information exploitation does not play a fixed and inflexible role in affordance perception, may be used to provide a methodologically useful way of partitioning the space of explanatory strategies that philosophers and cognitive scientists should use. Just how much cognitive load the environment bears in guiding context-sensitive intelligent behaviour depends upon a combination of the agent's skills and the complexity of the (global) environment perceived. With variation in temporal-depth of generative models across organismic complexity comes variation in free-energy minimizing strategies. As we have seen in chapter 4, common to all these strategies is the possibility for a PP agent to exploit information in the environment. For simple organisms (e.g., bacteria) and some plants, the survival of which might require only responding to the dynamics of their perceptual medium and nothing beyond it, exploiting information in the medium by deploying shallow functioning models need be the only satisfying option. For more complex organisms like us, although we may exploit models for minimal-perception when faced with certain undemanding tasks, in other contexts the kind of decoupled modulation of present experience by past experience that historical context sensitivity (HCS) describes may make the difference between reducible and irreducible free energy.

Conclusion

Located at the intersection of philosophy of biology and cognitive science, this thesis has aimed to expose some of the general mechanisms, principles and properties underwriting cognition at various levels of organismic complexity. Using the Free Energy Framework, predictive processing and some of the conceptual apparatus from ecological psychology in providing various perspectives from which to investigate strong life-mind continuity, over the course of the preceding chapters I have argued for a biogenically grounded manner of identifying and accounting for a wide range of intelligent adaptive behaviour in biological systems, spanning from that of minimal cognition in plants, to cognition in symbiotic associations, and finally to historically context sensitive cognition in humans. A few of the perplexing questions that have been addressed along the way to understanding how the properties and principles underwriting life have been enriched to as to arrive at cognitive processes have been "what are the explanatory limits of the ecological direct theory of perception?"; "How might bidirectional message passing be implemented in non-neuronal distributed minimal cognitive systems?"; "What is the relationship between metabolism and cognition?"; "What more is required of a biological system that engages in the minimization of free-energy to qualify as a biological cognizer?”

Life and mind are puzzling processes. Methodologically, the strong life-mind continuity thesis suggests that understanding either life or mind requires understanding the relationship between life and mind. This relationship will continue to be a central topic in the philosophy of cognitive science. One of the things which this thesis has shown in drawing from resources across disciplines is that any successful attempt at understanding the relationship between life and mind may very well require an expansive interdisciplinary effort between (not exclusively) philosophers, cognitive scientists, biologists, physicists, computer scientists, and system-theoretic scientists. The success of any such project has immediate impact not only upon how we view ourselves and our evolving relationship to the living world we are embedded in, but also how we go about recognizing the subtle and often extraordinary variations in the forms in which cognitive processes express themselves. It is only by being able systematically develop empirically grounded concepts to recognize these different forms and discover their possible common properties, mechanisms, and principles that we allow ourselves the opportunity to appreciate just how varied both life and mind can be.

The future of life-mind continuity research is promising and yet will remain an ongoing challenge given the difficult nature of the subject matter and the interdisciplinary demands which are placed upon its progress. That being said, I hope that I have shown that at least some progress can be made when jointly deploying the Free Energy Framework, predictive processing, and ecological psychology in the ways that I have proposed in this thesis.

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