What is cognitive about 'plant cognition'? [Preprint]

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Abstract

There is growing evidence that plants possess abilities associated with cognition, such as decision-making, anticipation and learning. And yet, the cognitive status of plants continues to be contested. Among the threats to plant cognitive status is the 'Representation Demarcation Challenge' which points to the absence of a seemingly defining aspect of cognition, namely, computation over representation with non-derived content. Defenders of plant cognition may appeal to post-cognitivist perspectives, such as enactivism, which challenge the assumptions of the Representation Demarcation Challenge. This points to an impasse in the debate over plant cognition as it collapses into perennial disagreements over the best way to conceptualise the very nature of cognition. I propose a path that allows us to bypass this quagmire by reconceiving the question of what is cognitive about 'plant cognition' in terms of a quest to map the many possible adaptive capacities and behaviours more-or-less associated with cognition, alongside their underlying processes and mechanisms. In turn, we can examine the degrees of similarity between plants and more paradigmatically cognitive creatures. The 'piecemeal approach' thus shifts attention away from the abstract and dichotomous question of whether plants are cognitive and towards a series of more precise questions about the many ways and extent to which plants possess features associated with cognition. Ultimately, the value of viewing plants through a cognitive lens may lie less in determining whether they are bona fide cognitive creatures and more in guiding research into concrete abilities and their underlying causes.

Keywords

cognition; plant cognition; plant neurobiology; mark of the cognitive; cognitive representation; mechanism; mechanistic explanation

§1. Introduction

Despite several decades of cognitive science, there is still no consensus on how to characterise cognition (cf. Akagi, 2018). Regardless, the conceptual and experimental tools of cognitive science are increasingly applied to creatures outside the animal kingdom, such as plants (e.g., Calvo et al, 2020), bacteria (e.g., Shapiro, 2007), and slime moulds (e.g., Vallverdú et al, 2018). Although such creatures lack the full suite of cognitive capacities associated with humans and other animals, they nonetheless display what is sometimes called 'minimal cognition'—perhaps less complex but distinctly *cognitive* abilities (for an introduction, see Brancazio, Segundo-Ortin & McGivern, 2020). Or so proponents claim. Others have protested the inclusion of these unorthodox subjects in the cognitive domain; to talk of plants, slime moulds and bacteria as 'cognitive' is to misapply the term, the thought goes, or to change the subject (e.g., Adams, 2018). This paper focuses on the controversy over plant cognition, the most complex of non-animal cases (that we know of) and which has received the most attention among targets of minimal cognition.

One reason to be sceptical of plant cognition is that plants lack a crucial ingredient for cognition according to a broadly cognitivist framework, roughly, computation over representation with non-derived content (e.g., Adams & Aizawa, 2001). Call this the 'Representational Demarcation Challenge' (RDC). The RDC may be resisted by embracing a 'post-cognitivist' theory, such as enactivism (e.g., Varela, Thompson & Rosch, 1997), that eschews the necessity of representational processes for demarcating cognition. The tension between cognitivist and post-cognitivist perspectives suggests that settling whether plants count as cognitive depends on first settling which is our best framework for understanding the underlying nature of cognition. A stalemate is then likely because disagreements between these accounts are longstanding and deeply embedded. This paper adopts an alternative approach to addressing plant cognition that does not depend on any particular view of the underlying nature of cognition, including whether it has a robust core, mark or essence. The 'piecemeal approach' states that the question of what, if anything, is cognitive about 'plant cognition' can be answered by discovering the extent of their 'cognitive features', defined, roughly, as adaptive capacities and underlying processes associated with cognition. Attention is shifted from the binary and totalising question of *whether* plants are strictly speaking cognitive to a multidimensional picture of the many ways and degrees to which plants possess cognitive features. In turn, the piecemeal approach focuses attention on the productive search for degrees of similarity between plant and animal capacities typical of cognition (memory, decision making, learning etc.), and their underlying processes and mechanisms (e.g., electrical signalling systems, action potentials, neuromodulators etc.), at multiple levels of organisation.

The paper proceeds as follows. §2 introduces the idea of plant cognition and surveys some recent findings from 'plant neurobiology' and cognitive science. §3 presents the Representational Demarcation Challenge, which questions the cognitive status of plants because they lack the representational processes that characterise cognition. §4 discusses the possibility of resisting the RDC by appealing to a non-representational characterisation of cognition by way of a post-cognitivist theory, such as enactivism. §5 defends the piecemeal approach. This perspective is preoccupied with the extent to which plants possess (many possible) features typical of cognition, and the degrees of difference between plants and paradigmatically cognitive systems, rather than dichotomous membership of the cognitive club. Drawing on this approach, I close by suggesting that the primary value of viewing plants from a 'cognitive stance' lies in its power as a research heuristic, guiding the search for certain abilities and their underlying causes.

§2. Plant Cognition

The debate over whether plants count as cognitive stems from growing evidence from the plant sciences for their seemingly cognitive-like abilities. The emerging disciplines of plant neurobiology and cognitive science (e.g., Brenner et al., 2006; Calvo & Trewavas, 2020) indicate that plants exhibit a multitude of paradigmatically cognitive capacities or behaviours, including perception, communication, kin recognition, decision-making, anticipation, learning, risk sensitivity, and mimicry (Calvo, 2016; Calvo et al, 2020; Segundo-Ortin & Calvo, 2022). In turn, processes associated with cognition, namely information-sensitive processes, such as adaptive responses to a range of biotic and abiotic factors, information storage, intra- and inter-organism communication, and signal integration/propagation, are invoked to explain these plant capacities (e.g., Trewavas, 2014). Even relatively long-known abilities, like the delayed response to touch following the onset of appropriate conditions in pea plants (*Pisum sativum*), seem to indicate the presence of information storage and retrieval (Riehl & Jaffe, 1984). Specific mechanisms underlying cognition in humans and other animals, such as action potentials (e.g., Canales et al., 2018) and neurotransmitters also increasingly appear to play a key role (e.g., Baluška et al., 2020; Miguel-Tomé & Llinás, 2021). Thus, there appear to be significant similarities between plants and known cognitive systems.

Such apparent similarities have led some plant scientists and philosophers to attribute cognition to plants. To appreciate this further, first consider the example of decision-making in plant foraging behaviour. According to Cahill et al (2010), when plants (*Abutilon theoprasti*) grow alone, they display maximum root distribution and rooting breadth (independently of how resources are distributed). However, when a competing plant is introduced, subjects switch to restrained foraging strategies, depending on resource distribution. Root placement strategy across the plant thus appears determined by the integration of information concerning resource distribution plus the presence of competitors. Other examples of intelligent foraging include the prioritising of certain condition combinations (e.g., light and warm soil) over others (e.g., the presence of competitors) (Trewavas, 2014).

Second, consider anticipatory behaviour. It is widely accepted that certain plants (*Lavatera cretica*) not only track the sun during the day but adjust their position during the night to face the direction the sun will rise the following morning. Moreover, this behaviour is retained for several days without solar tracking (Schwartz & Koller, 1986). Calvo & Keijzer (2009) interpret this as showing the capacity for a complex off-line response. Other examples of anticipatory behaviour include the apparent preference of pea plants (*Pisum sativum*) for root growth in areas of soil with increasing levels of nutrients over areas with higher absolute but non-increasing levels of nutrients (Novoplansky, 2016). Segundo-Ortin & Calvo (2019) take such evidence to indicate that plants not only respond to the magnitude of a variable but also its temporal and relational profile with respect to other variables (following Silvertown & Gordon,1989).

Finally, consider learning. So-called 'sensitive plants' (*Mimosa pudica*) have been shown to habituate to stimuli. In work by Gagliano et al (2014), using methodologies adapted from animal studies, mimosa were exposed to repeated 15cm falls, causing the plant to fold its leaves. After several instances of the (non-harmful) falls, subjects ceased leaf folding, and maintained this response for some time after. Having excluded the possibilities of sensory adaptation and motor fatigue, the experimenters interpreted these findings as suggesting that leaf-folding behaviour exhibits habituation in response to environmental conditions. Recent research also tentatively indicates pea plants may be capable of associative learning (Gagliano et al, 2016), although there have been challenges in replicating the findings and studies are ongoing at the time of writing (for debate, see Markel, 2020ab; Gagliano et al, 2020).

In addition to seemingly cognitive capacities or behaviours in plants, claims are made about significant continuities in corresponding mechanisms across plants and animals. The catching mechanism in Venus flytraps (*Dionaea muscipula*), for instance, has long been known to require two stimulations of 'sensitive hairs' or 'trigger hairs' situated on the inner surface of the plant's leaf (e.g., Hedrich & Neher, 2018).[1] When one of these mechanoreceptor hairs is touched, the plant continues to register this stimulation for up to twenty seconds through a stored electrical charge. If a hair is touched again within a certain interval, a threshold is met, causing an action potential to stimulate cells, forcing the organ forming the trap to close. The depolarisation underlying this mechanism is also fundamental to neural signalling in animals. Thus, similar electrochemical gradients are thought to be involved in the storage and retrieval of information—arguably, a form of memory—across phyla. Plant cells may also use the same proteins for cell-to-cell signalling that function as neuroreceptors in animal nervous systems and are crucial for memory and learning (for discussion, see Wudick et al, 2017). Frameworks from cognitive science, such as predictive processing, have also been used to indicate analogous principles of organisation in plants and animals (e.g., Calvo & Friston, 2017). Electrical signalling and its relationship to the coordination of plant behaviour (e.g., Yan et al, 2009) is another broad but illustrative area where borrowing tools for explaining animal cognition seems promising, especially those of information communication research (e.g., sender-receiver models; Shannon 1948; Skyrms, 2010).

Despite cross-kingdom similarities, so-called plant cognition exhibits idiosyncratic features. For instance, plants have no central control organ, or nervous system (but see Miguel-Tomé & Llinás, 2021), operating instead through a distributed architecture of interacting electrical, hydraulic, and chemical signalling pathways (Huber et al, 2016). This is implemented across a network of semi-autonomous roots and shoots (Calvo, 2016; Calvo & Trewavas, 2021), implicating properties of 'swarm intelligence'—the adaptive behaviour of self-organized systems emerging from a population of simple elements interacting locally with each other and their environment (Ciszak et al, 2012). Non-determinate growth and a plastic phenotype are also key to plant behaviour, using

[1] The value of two requiring two stimulations is likely that it ensures prey is large enough to warrant the energy expenditure of closing and/or it guards against accidental triggering by non-prey (false positives).

‘remodelling’ (changing material properties), and ‘morphogenesis’ (changing shape) to act flexibly in response to biotic and abiotic factors within a dynamic environment. Finally, there is growing evidence that intelligent behaviour in plants depends on intimate reciprocal relationships with mycorrhizal networks and the web of inter-plant communication they facilitate (e.g., Gorzelak et al, 2015). Thus, research reveals similarities in plants and animals, whilst undermining zoo-centric assumptions about the architecture and embodiment required for functions associated with cognition.

The small handful of examples surveyed so far gesture toward the variety of plant abilities and processes that resemble those labelled ‘cognitive’ in animals. Hence, plants are often described as performing ‘minimal cognition’. The term is not without controversy, however. Lyon (2020), for instance, worries that ‘minimal’ admits the unwarranted implication that creatures outside *Animalia* possess an attenuated version of full-blown cognition. Setting aside the merit of such concerns, I use ‘minimal cognition’ to refer to the simplest systems capable of exhibiting cognition, not to qualify the extent to which a function counts as cognitive. This is comparable to describing biological cells as ‘minimal living systems’—not implying cells are less alive but that they are the simplest unit exhibiting the features of life.[2] Furthermore, we can talk of ‘minimal cognition’ whilst remaining sensitive to problematic generalisations about the relative sophistication of abilities in plants compared to animals; as some ethologists warn, we should not assume cognition can be measured along a single scale of supremely stupid to super smart (e.g., de Waal, 2016). Cognition is plausibly an adaptation (or set of adaptations) made of many parts that are responsive to varying selective pressures and so one-dimensional scales may simplify complex evolutionary products. Indeed, as I shall argue below, we should remain sensitive to both *how much* and *in what ways* (and not just *if*) plants resemble more paradigmatically cognitive creatures.[3]

Research into plant and other cases of so-called minimal cognition has sparked renewed debate over how to characterise cognition (e.g., Adams, 2018). This parallels the long-running discussion over the physical boundaries of cognition that began with Clark & Chalmers (1998) paper on the extended mind hypothesis. In their seminal discussion, the authors make a case for including aspects of an agent’s environment as a constitutive part of cognition. In the years since, opponents have endeavoured to confine cognition to the cranium, and in doing so, appealed to a fundamental ‘mark of the cognitive’. A similar challenge can be leveraged against those who wish to allow cognition to extend, not beyond the body, but across the tree of life.

§3. The Representation Demarcation Challenge

One compelling argument against plant cognition stems from careful consideration of what plausibly demarcates cognitive from non-cognitive processes i.e., what determines membership into the same category or kind referred to when ordinarily talking about cognition. According to the ‘Representation Demarcation Challenge’ (RDC), evidence of sophisticated plant abilities falls short of evidence for cognition

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[2] There are other contexts where ‘minimal’ does not imply a diminutive form, for example, in the context of ‘minimal model’ explanations (Batterman, 2014).

[3] It is becoming common to talk of ‘basal cognition’, evading any unwelcome connotations of ‘minimal’ (e.g., Lyon et al, 2021). The comparative value of these terms needn’t worry us here.

unless we can demonstrate accompanying representational processes of the appropriate sort, which many proponents of plant cognition themselves question (e.g., Maher, 2017). Otherwise, the burden is on the proponent of plant cognition to show why plant processes count as cognitive—as opposed to, say, merely physiological—in the same sense as paradigmatic cases of cognition, such as human mind reading. The RDC is here reconstructed from explicit views towards minimal cognition (e.g., Aizawa, 2014a, 2014b; Adams, 2018) as well as extrapolatable trends within the longer-running extended mind debate (e.g., Adams & Aizawa, 2001; Adams & Aizawa, 2010; Aizawa, 2017). In turn, these build on a tradition of associating cognition with a type of computation (e.g., Newell & Simon 1976; Johnson-Laird 1983) and identifying minded entities by appealing to computation over representation (e.g., Pylyshyn 1984; Fodor & Pylyshyn, 1988).[4]

The RDC is supported by two primary and mutually supporting considerations: (1) the plausibility of 'cognitivism' providing the grounds for demarcating cognition given its general success as a framework for understanding cognition; and (2) the capacity of cognitivism to draw a principled distinction between cognition and behaviour which some regard as a virtue. Let's visit these in turn.

The RDC draws on a cognitivist tradition, which conceives cognition in terms of computation over representation with non-derived content. This originally took the form of the 'classical computational theory of cognition' (CCTC), or 'classical computational theory of mind' (e.g., Putnam, 1967). The CCTC models cognition in terms of the processing of natural symbolic representations (inner 'syntactic states' bearing content), in accordance with formally specifiable rules. Cognitive capacities are taken to be caused by the storing, combining, re-combining and erasure of discrete, atomic symbol tokens which combine to make complex symbol tokens. Such symbol manipulation is often taken to conform with language-like rules within an algorithmic structure (Fodor, 1975). However, for present purposes, a wider definition of cognitivism that does not entail the CCTC is more appropriate. Cognitivism here encompasses any theory of cognition that centres computation over representation with non-derived content. Many points of interest beg for further exploration here, but one noteworthy trend is the attempt to understand computation in terms of a mechanism manipulating medium-independent vehicles per a rule, where such functions are not necessarily digital or language-like (e.g., Piccinini, 2020).[5] In short, one may subscribe to cognitivism, in its broadest sense, without endorsing the CCTC. This is relevant because cognitivism, in its broadest sense, remains one of the most popular positions in philosophy of cognition and practising cognitive science. Thus, the RDC does not arbitrarily appeal to one of many theories of cognition but to an orthodox philosophical and scientific framework.

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[4] Cognitivists are not committed to defending the RDC. For example, one might think cognitivism is our best theory for exemplary cases of cognition but grant the existence of non-orthodox cases that do not involve representation (see §5 for related discussion).

[5] One complication arising from these accounts is the role of representation in computation. Some proponents, including Piccinini (2020), hold that computation is not necessarily semantic (although see Maley, 2018), yet they maintain that neural computation does involve representation. Nevertheless, the non-semantic nature of computation at least opens the door for a theory in which cognition is computational but not representational (e.g., Dewhurst, 2018).

Cognitivism supplies the ingredients for the RDC. Paradigmatic cases of cognition involve a distinctive class of representational processes that even non-human animals may possess (e.g., Curruthers, 2004) but which plants seem to lack. Thus, plants appear to lack a characteristic ingredient of cognition. According to Adams (2018), for instance, any apparent 'learning', 'decision-making' or 'memory' in plants must refer to something different than learning, decision-making or memory in humans because the former abilities are not underwritten by the same process as the latter, in accordance with cognitivism. Notice that this sceptical stance does not dispute claims concerning the rather impressive abilities of non-zoological creatures. Rather, it attacks the logic of attributing cognition to them despite the evidence for these abilities.

An apparent virtue of the RDC is that it preserves an appealing distinction between cognition and behaviour, by drawing on cognitivism. Cognition is a type of process (computation over representation) responsible for the behaviours we associate with cognition, the thought goes, and not itself a set of least behaviours.[6] This avoids the purported paradox that results from treating cognition both as a kind of behaviour and the cause that explains that behaviour. As noted by Aizawa (2017),

> Perhaps Cognitivism is mistaken, but one can at least see how it leads to the plausible view that cognition is distinct from behavior, that cognition is among the causes of behavior, and how we might understand cognitive behavior as the contingent product, in part, of cognitive mechanisms. (p. 4286)

In this vein, the RDC, at a minimum, puts pressure on the proponent of plant cognition to explain why the sorts of plant abilities being unearthed should be classified as cognitive; why we should assign, say, plant foraging behaviour, however sophisticated, to the same category as human mind-reading?

Distinguishing between cognition and behaviour also accounts for the difference between behaviourism and cognitive science (Aizawa, 2018). The cognitive revolution, as exemplified in Chomsky's repudiation of Skinner, ushered in an era in which capacities like language learning were explained by appealing to previously unconscionable inner, representational states. A lurking worry then is that those eager to ascribe cognition to plants too often take evidence of behaviour as evidence of cognition, but this conflates behaviour with its causes. Thus, the proponent of the RDC demands to see evidence for cognition rather than merely evidence of sophisticated behaviour. Cognitivism, in turn, supplies a concrete, positive answer as to what that evidence would look like, namely, evidence of computation over representation.

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[6] Of course, one might question the value of the behaviour/cognition distinction and some post-cognitivist perspectives appear to willingly reject it. However, it is not only cognitivists who castigate characterisations of cognition in terms of behaviour. Barandiaran & Moreno (2006) argue against 'behavioristic characterizations' in favour of an understanding, following an enactivist tradition, in terms of the adaptive-autonomy of nervous systems. Citing Searle's (1980) Chinese Room thought experiment, the authors share the fear of conflating genuine cognition with its mere simulation at a behavioural level. See §4 and §5.3 for related discussion.

§4. Post-cognitivist perspectives

One way to counter the Representation Demarcation Challenge is to insist that plants do exhibit the representational processes that cognitivism posits (for related discussion see Garzon, 2007). However, this move faces a few challenges. First, the plant sciences rarely explain plant behaviour by appealing to processes of computation over representation which provides some prima facie reason to question the value of computational explanations. Second, whilst the plant sciences do occasionally describe plants as computing (e.g., Kawano et al, 2012; Bassel 2018; Meroz, 2021), on closer inspection, this literature often confuses the success of computational modelling of plants for physical computation performed by plants themselves or otherwise appeals to an exceptionally deflated notion of computation [citation redacted for anonymity]. Third, most existing defences of plant mentality or cognition either do not appeal to computation over representation with non-derived content or explicitly offer post-cognitivist accounts of cognition, often suggesting that a defence of plant cognition requires abandoning cognitivist assumptions (e.g., Segundo-Ortin & Calvo, 2019). Fourth, to my knowledge, no comprehensive defence of plant computation currently exists. These challenges are far from conclusive. However, they collectively indicate concern for any defence of plant cognition dependent on the claim that plants perform computation over representation in the requisite sense. For these reasons, I will grant for this discussion that there is insufficient evidence that plants perform the right variety of representational processes.

Another possible counter to the RDC is to claim that cognitivism is false, and representational processes offer a poor criterion for demarcating cognition. If representational processes do not explain at least some cognition for even paradigmatic cases (such as human cognition), then we must abandon representation-based criteria for cognition. Indeed, some post-cognitivist frameworks, such as enactivism (e.g., Varela, Thompson & Rosch, 1991), reject the necessity of representation and computation for cognition (but see Villalobos & Dewhurst, 2018). According to enactivism, mind and cognition should be characterised, in the first instance, in terms of the dynamic, coupled interactions between an organism and its environment that aid the self-organized persistence of the organism. Thus, there is a continuity of life and mind, with basic biological interactions forming the basis for more complex (but not necessarily *more cognitive*) cognitive functions. In turn, cognition is not fundamentally representational (in fact, the very concept of subpersonal representation may be erroneous, e.g., Hutto & Myin, 2013). If enactivism is correct, then representation would be ill-suited for characterising cognition.

More generally, as confidence in cognitivism and the power of representation to explain cognition has eroded, alternative (sometimes overlapping) approaches have emerged that either explicitly offer their own criteria for cognition or imply one by indicating conditions for its genuine emergence. Options include sensorimotor (e.g., Van Duijn, Keijzer, & Franken) and free energy approaches (e.g., Kiverstein & Sims, 2021). Another prominent perspective that has received attention in the debate over plant cognition is the ‘biogenic approach’, which incorporates some other post-cognitivist accounts of cognition (Lyon, 2006). It states that cognition should be understood first and foremost as a biological process and part of a universal biological capacity for environmental interaction, thus incorporating plants (for a response to the biogenic approach from a cognitivist perspective, see Adams, 2018).[7]

Existing defences of plant cognition sometimes appeal to such post-cognitivist theories. For example, Segundo-Ortin & Calvo (2019), in response to Adams (2018), invoke an enactive-cum-ecological perspective, conceiving of cognition in terms of ‘intelligent behaviour’ and underscoring an organism’s interaction with its environment ‘in adaptive, flexible and sophisticated ways so as to maintain their systemic autonomy’ (p. 70).[8] The authors reject the claim that cognition must involve semantically evaluable representations (p. 69), and suggest that to assume representation demarcates cognition begs the question against non-representational theories. A post-cognitivist defence of plant cognition is also reflected, for instance, in Maher’s (2017) treatise on plant minds (a close approximation to plant cognition), which argues that plants do not possess minds according to representationalist criteria: “the best case against plant minds […] depends on the claim that minds require representations" (p.109). For Maher, however, enactivism offers a more promising avenue for understanding cognition, and plants *do* possess minds according to enactivism (cf. Froese & Di Paolo, 2011).

The strategy of defending the cognitive status of plants by appealing to a non-representational theory of cognition more generally faces a limitation, owing to its reliance on the affirmation of ongoing, post-cognitivist projects. Many sympathisers of the RDC will remain sceptical of plant cognition if it requires rejecting cognitivism.[9] Some defenders of post-cognitivist approaches, meanwhile, will suspect that the RDC gets off on the wrong foot, assuming an erroneous conception of even human cognition. The ensuing conflict indicates that resolving the debate over plant cognition by appealing to extant theories requires retreating into the longer standing debate about our best framework for explaining cognition. Such debates, I suggest, typically assume (often implicitly) that cognition is a category or kind possessing a relatively robust core, mark or essence that provides it with well-delineated boundaries (see §5). A stalemate looms, reminiscent of some quarters of the extended mind literature, generated by deep-seated disagreements about the best way to conceptualise the nature of the cognitive kind (for sample discussion, see Menary, 2010).

A withdrawal into the perennial debate over the underlying nature of cognition, predicated on which is the best theory or framework in cognitive science, may be the

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[7] In some guises, the biogenic approach seems more concerned with constraints on empirically investigating cognition and less on the underlying character of cognition *per se* (though the former has implications for the latter). The hermeneutic challenges surrounding the biogenic approach needn’t preoccupy us here, however.
[8] As the authors acknowledge, some enactivists remain sceptical of plant cognition (e.g., Froese & Di Paolo, 2011), so even from within this post-cognitivist framework there is room for disagreement about the boundaries of cognition.
[9] I take it that some of the positions mentioned, such as that of Segundo-Ortin & Calvo (2017), can be reinterpreted through the lens of the piecemeal approach set out below. More generally, I take it that enactivists (alongside cognitivists) are not necessarily committed to cognition possessing a core, essence or mark as explored below. In any case, the appeal to particular post-cognitivist theories for redrawing the borders of cognition (in contrast to cognitivism) is illustrative as a contrast to the piecemeal approach.

only outcome for the debate over plant cognition, however regrettable. This would be worth acknowledging; it matters if settling what, if anything, is cognitive about 'plant cognition' collapses into deeper convictions about the relative merits of representational versus non-representational conceptions of cognition. Nevertheless, I propose an alternative approach for addressing the cognitive status of plants that does not depend on any theory or framework addressing the fundamental nature of cognition per se. Rather, it focuses on piecemeal questions regarding plant cognitive capacities or behaviours (or at least those capacities and behaviours ordinarily caused by cognitive processes), their underlying processes or mechanisms, and their degree of similarity to quintessential cases of cognition. As we shall see, this approach helps to show that many of the interesting questions about 'plant cognition' are left largely untouched, even if the RDC is correct.

§5.0 The piecemeal approach

Let's take stock: we have seen evidence for cognitive abilities in plants (like learning) and for mechanisms underpinning these that are similar to those underpinning cognition in creatures with nervous systems (like action potentials for electrical signalling). Nevertheless, we saw a challenge to the idea that plants cognise in the same sense as humans and other animals (paradigmatically cognitive creatures) because they lack a core characteristic of cognition, roughly, the right kind of representational process. Defenders of plant cognition can respond by appealing to a post-cognitivist account that offers alternative criteria, encompassing plants, such as dynamic coupling between organism and world. The question of what, if anything, makes 'plant cognition' cognitive would thus appear to lapse into a familiar debate between entrenched frameworks. The remainder of this section will explore an approach to plant cognitive status that does not depend on the success of any one framework for conceptualising cognition per se, like cognitivism or enactivism. The 'piecemeal approach' shifts attention away from the dichotomous and totalising question of *whether* plants are cognitive, and towards a series of precise questions about *what* 'cognitive features' plants exhibit and so too the *degree* of resemblance between plants and undisputed cases of cognition. The aim is not a binary sorting of creatures into the cognitive and non-cognitive but a multidimensional view of how capacities or behaviours and their underlying causes or mechanisms compare across taxa.

§5.1 Two approaches to plant cognitive status

The central claim of this section is that the question of what, if anything, is cognitive about plant cognition need not be interpreted as asking whether plants belong to the same 'cognitive kind' referred to when investigating paradigmatic cases of cognition, assuming there is a well-delineated kind. Instead, the question can be interpreted as a query about the many possible 'cognitive features' exhibited by plants. A cognitive feature is, roughly, a capacity or behaviour (such as associative learning) ordinarily caused by a bona fide cognitive process or mechanism (if cognition is defined by a distinct class of cause, as the RDC suggests), a capacity or behaviour more-or-less prototypical of cognition (if cognition is a graded notion, a cluster concept or a plurality of related kinds), or a process or mechanism that partially causes such capacities or behaviours in typical cases (such as information integration).[10] In short, a cognitive feature is a typical—though perhaps not necessary or sufficient—element of cognition. Taxa may thus exhibit cognitive features even if they are not card-carrying members of the cognitive club. We can, in turn, compare the *degree* of similarity in cognitive features across plants and other taxa. In presenting the piecemeal approach, I hope to defang the RDC by showing that the issue of plant cognitive status need not be interpreted as being about whether plants fall into precisely the same kind referred to when discussing ordinary cases of cognition. I will suggest, in fact, that even if the RDC is correct, many or most of the interesting questions about 'plant cognition' remain (where 'plant cognition' refers to the 'cognitive features' of plants).

As we have seen, much philosophical debate around so-called plant cognition centres on the cognitive status of plants, or the question of what, if anything, is cognitive about plant cognition. The issue of plant cognitive status can be interpreted as a dichotomous question addressing whether plants are members of the 'cognitive kind', that is, the same kind referred to when we ordinarily talk about cognition. The RDC is most straightforwardly seen as a test to plant membership of the cognitive kind that demands plants meet a relatively well-specified set of conditions. Likewise, when applied to this debate, enactivism (as well as sensorimotor, free energy, biogenic and other rival accounts to cognitivism) can be interpreted as challenging the criteria for the cognitive kind assumed by the RDC by establishing their own terms for membership. Ultimately, the issue is whether plants fall into the well-circumscribed category of cognition, and this is settled by fixing its criteria then determining whether plants meet them. Let's call this the 'cognitive kind approach'. There is, however, another way of interpreting the issue of plant cognitive status. Instead of focusing on whether plants belong to *the* category of cognition, as we ordinarily mean it, one can instead ask which (of many possible) phenomena associated with cognition plants exhibit i.e., what 'cognitive features' they manifest (putting aside for a moment whether there is *a* cognitive kind, for reasons we will see). The issue becomes not *whether* plants fall into the category of cognition but *in what ways* and to *what degree* plants instantiate features of cognition, and in turn, how much they resemble undisputed cases of cognition.[11] Let's call this the 'piecemeal approach'. As we will see, the piecemeal approach is neutral not only towards what defines cognition per se but whether there even is robust, well-delineated kind.

If the piecemeal approach says that we can approach plant cognitive status by investigating their cognitive features—elements typical of but not necessarily required for cognition—then the question remains as to what these features are. Our previous discussion on accounts of cognition that dispute the relative importance of distinct abilities versus their causes indicates two obvious candidates: (1) the capacities or

[10] The piecemeal approach is consistent with a rejection of the idea that cognition possesses a sufficiently robust core, mark or essence and is instead a graded notion, cluster concept or plurality of kinds. See §5.2.

[11] This is arguably what plant scientists studying 'plant cognition' are principally concerned with i.e., the sorts of capacities or behaviours and the kinds of processes or mechanisms that plants are capable of. Indeed, empirical investigations into cognitive or cognitive-like capacities, such as decision-making, and their mechanisms, such as neurotransmitters, do not depend on demonstrating that plants possess 'cognition per se'. To this extent, the piecemeal approach reflects scientific practice. However, I make no claims about the presumably diverse views on plant cognition among the community of scientists studying 'plant cognition'.

behaviours exhibited by plants, and (2) their underlying processes or mechanisms. This is reflected in the structure of contemporary cognitive neuroscience which aims (1) to explain a set of phenomena more-or-less associated with cognition, (2) by uncovering its underlying causes and constituents.[12] For example, cognitive scientists study the capacity of different animal species for associative learning and investigate the biological mechanisms responsible at multiple levels of biological organisation from sub-neural processes to the whole nervous system (cf. Piccinini, 2020).

The piecemeal approach thus indicates that plant cognitive status can be addressed by mapping (1) which adaptive capacities or behaviours more-or-less associated with cognition plants possess and (2) how similar their underlying processes or mechanisms are to paradigmatic cases. It thus focuses attention on a series of empirically tractable questions such as if plants are capable of associative learning (or, if one prefers, whether plants exhibit the behavioural hallmarks of associative learning i.e., novel conditioned responses to stimuli), and the degree to which plant behaviour depends on neurotransmitters modulating electrical signalling analogously to activity in animal nervous systems. As we have seen, there is mounting evidence that plants exhibit behaviours studied by cognitive science and ordinarily labelled as ‘cognitive’ (e.g., learning, memory and decision-making) and that they exploit mechanisms that are crucial for cognition in humans and other animals (e.g., action potentials and neurotransmitters). From the perspective of the piecemeal approach, the point is not that this evidence affirms affiliation with the cognitive club, but that it answers concrete questions about what cognitive capacities (or capacities typical of cognition) and what cognitive mechanisms (or mechanisms ordinarily involved in cognition) plants possess. In turn, the evidence contributes to a nuanced picture of how plants and animals compare in features typical of cognition.

With the piecemeal approach, we witness a shift from the binary and totalising question of *whether* plants are cognitive to the many questions of *how* and *to what degree* plants manifest more concrete cognitive features (and thus their degree of resemblance to paradigmatically cognitive systems). By analogy, consider two questions one might ask about the relationship between viruses and life. One question is *whether* viruses are alive, requiring a yes/no answer. Another is *how* and *in what ways* viruses possess features associated with life or resemble paradigmatic cases of living creatures (cf. Villarreal, 2004). Notice that simply knowing whether viruses are alive or not (assuming life even has a robust core, mark or essence—see below) does not tell us in what ways and the degree to which viruses resemble unquestionably living systems.

§5.2 Criticisms & Clarifications

Several criticisms of the piecemeal approach stand out, allowing the position to be clarified. The first and most obvious complaint is that the approach fails to address what makes a ‘cognitive capacity’ or ‘cognitive process’ count as a *cognitive* capacity, or *cognitive* process; or if one prefers, what underlies all the capacities or processes typical of cognition (e.g., see Adams, 2010). This is a question that theories like

[12] I use ‘mechanism’ in its most generic sense, making no commitment to the stronger and diverse claims of the mechanistic model of explanation, as explicated by ‘new mechanists’ (Machamer, Darden, & Craver, 2000; Glennan, 2002; Bechtel & Abrahamsen, 2005; Craver, 2007; Bechtel & Richardson, 2010).

cognitivism are well-placed to answer: phenomena like decision-making, memory and learning are cognitive capacities or (legitimately) associated with cognition because they are (in paradigmatic cases, anyway) underwritten by a distinct class of process that individuate the cognitive kind (roughly, computation over representation). Without appealing to some theory like cognitivism, the piecemeal approach takes for granted a set of phenomena associated with cognition without explaining why *these* (and not *those*) phenomena fall under the umbrella of cognition. This challenge allows us to clarify the ambitions of the piecemeal approach.

By itself, the piecemeal approach is not a rival to cognitivism or any other account that is appealed to when explicating the nature of cognition. Rather, the piecemeal approach sidesteps the issues of what defines the cognitive kind, or if it even exists. To unpack this further, notice that the piecemeal approach is consistent with two views about the nature of cognition: (i) the ‘core view’ and (ii) the ‘no-core view’ (borrowing terms from Rodriguez, 2020; Figdor, 2020). According to the core view, cognition possesses a sufficiently robust core, mark or essence that delineates a distinct kind. Plants are thus either cognitive (in the usual sense) or they aren’t, based on whether they possess this core, mark or essence. In its most straightforward guise, the RDC assumes the core view, drawing on cognitivism to clarify what that core is. However, the piecemeal approach shows that even if the core view is correct, whichever side plants fall, a host of questions regarding their relationship to typically cognitive features remains unanswered, or similarly, a host of questions about the relationship of plants to the cognitive kind remains unanswered. One can thus ringfence some cognitive features (as we've defined them) and reserve the 'cognitive' label proper for creatures possessing these, whilst accepting the importance of discovering related (but not sufficient) features of cognition possessed by excluded taxa.

For example, suppose the category of cognition (as we ordinarily mean it) is defined by computation over representation with non-derived content, that we have reason to doubt that plants instantiate these processes, and therefore plants are not truly cognitive. Now recall the outstanding controversy over associative learning experiments in plants with some experiments claiming evidence to support conditioned sensitisation (conditional pairing of neutral and non-neutral stimuli) and others raising doubts about the replicability of those experiments. Notice that knowing whether plants are truly cognitive would not resolve this outstanding empirical question—it would not tell us whether plants exhibit this behaviour associated with cognition in animals. Even if one rejects such hypothetical behaviour as *true* learning because true learning requires the right kind of underlying cause (computation over representation), we can still ask if plants exhibit analogous behavioural patterns that ordinarily operationalise learning in animals.

The core view assumes cognition has a sufficiently robust core, mark or essence but not everyone agrees. According to the no-core view, cognition is not all or nothing kind. To borrow from Schwitzgebel (2020), the no-core view rejects the idea that “psychological properties travel in groups, such that an entity either has the whole mind package or lacks mentality altogether” (p. 671). Instead, cognition is a graded notion, a cluster concept or a plurality of related kinds. If the no-core view is correct, there is no underlying element that unifies all genuine instances of decision-making, memory or learning (this does not mean there is no family resemblance or set of more-or-less common properties). Several positions fall under the no-core view (e.g., Allen, 2017; Ramsey, 2017; Rodriguez, 2020; Schwitzgebel, 2020; Hiernaux, 2021). Whilst they differ in their details, they all reject the idea that cognition has a fixed core, mark or essence. We need not worry about their differences here. The point is that the core view, however conceived, is not a given.

For illustrative purposes, consider Ramsey's (2017) view that depicts cognition as a cluster concept. For Ramsey, cognition refers to a fuzzy set of capacities, behaviours or processes more-or-less associated with the mind, "with certain prototypical processes in the center and more obscure or atypical processes and states on the periphery" (p. 4208). Cognition is thus a cluster concept. Mind-reading and perception, for instance, both appear to belong in the cluster (evidenced by their appearance across cognitive science textbooks), though perhaps mind-reading may be regarded as more quintessentially 'cognitive' considering the historic distinction between perception and cognition.[13]

If the no-core view is correct, then asking *if* plants meet the core of cognition is not a meaningful question. In a mirror image to the core view, simply knowing that cognition is a graded notion, cluster concept or a plurality of related kinds does not tell us much about plant capacities or how similar their underlying mechanisms are to animals. It does not, for instance, tell us whether experiments that seemingly support associative learning (or at least its corresponding behavioural patterns) are replicable, or just what the functions of neurotransmitters are in plants.

Consider again, our two questions about viruses and life: *whether* viruses are alive, and *how* and *in what ways* viruses possess features associated with life or resemble paradigmatic cases of living creatures. The first question arguably relies on a 'core view' of life. However, a core view of life is not a given. The second question is neutral regards whether a core or no-core view of life is correct. Thus, one might be persuaded that life has some essential characteristics—say, for the sake of illustration, the capacity for reproduction—and use these to determine whether viruses are alive, once and for all. Alternatively, one might think life is a fuzzy concept or collection of overlapping concepts with vague boundaries (e.g., Van Regenmortel, 2016). Neither view by itself tells us about the many ways in which viruses are like and unlike undisputedly living creatures like cells, centipedes and chanterelles.

A second concern with the piecemeal approach is that, though concerned with both behaviours and their underlying mechanisms, without some unifying type of underlying process or mechanism (like computation over representation), then behaviour associated with cognition is decouplable from its causes and we again blur the behaviour/cognition distinction, and so too the difference between behaviourism and cognitive science. However, the piecemeal approach is focused on a series of concrete questions regarding the cognitive features of plants—and so too the degree of similarity between plants and paradigmatically cognitive systems—and is neutral as to whether

[13] The concept of cognition has become more liberal over time (cf. Akagi, 2018); once restricted to abilities associated with deliberative thinking, capacities such as perception are now included. At first pass, those abilities associated with the more restricted notion are the more prototypically cognitive. Regardless, how to understand the centrality of an ability to the cluster concept comprising cognition (which I am not defending) is not essential for our discussion.

cognition is a kind defined by a type of process (like computation over representation). Nothing prevents one from following the piecemeal path whilst retaining that plants are only *truly* cognitive if their cognitive features are underwritten by a process meeting the criteria for the cognitive kind (e.g., computation over representation), thus preserving the cognition/behaviour distinction. Equally, it is compatible with a view that rejects a meaningful distinction between behaviour and its causes, or with a view that maintains a distinction between behaviour associated with cognition and its causes, identifies the latter with cognition, but insists that there is no one, well-delineated criterion marking certain causes as cognitive (for related discussion, see Ramsey, 2017).

A third concern about the piecemeal approach is that it naively suggests cognitive capacities and behaviours are identified in some straightforward and perhaps theoretically neutral way. The comparative psychology literature underscores that identifying the same capacities and behaviours across different organisms is challenging given persistent disagreements about how to conceptualise cognitive functions and how to evidence their existence. For example, comparative psychology is plagued by debate about whether animals possess various capacities—including causal cognition, theory of mind, and mental time travel—given disagreements about what the phenomena amount to, and what counts as evidence. Identifying some set of observed plant behaviours as, say, associative learning, is likely to face similar setbacks. There are at least two overlapping responses we might consider.

First, the kinds of abilities in plants under consideration are generally of a less complex sort and, I suspect, at least *less* susceptible to the degree of controversy found in animal psychology. For example, determining whether plants are capable of associative learning requires cautious experimentation (Markel, 2020ab) but the possibility of demonstrating the capacity to develop novel conditioned responses to stimuli in garden peas (Gagliano et al, 2016) seems less conceptually fraught as, say, demonstrating theory of mind in chimpanzees (Call & Tomasello, 2011). Second and more substantially, there are approaches in comparative psychology that acknowledge these worries and advise us to sidestep the question of whether a species categorically possesses some ability and instead develop a multidimensional picture that maps similarities and differences (in a manner that respects the principle of incremental evolution). Such approaches sit well with the spirit of the piecemeal approach that emphasises a shift from relatively abstract and dichotomous concern for categorisation to more precise questions with clear empirical content. Starzack & Gray (2021), for instance, focus on the contentious example of causal cognition in animals, recommending we focus on empirically tractable questions concerning central parameters associated with causal cognition (‘sources’, ‘integration’, and ‘explicitness’). They then recommend we map these to a three-dimensional conceptual space that allows for fine-grained comparisons between species. If this view is correct, we needn’t preoccupy ourselves with the question of whether some creatures categorically possess a somewhat ambiguous capacity (such as associative learning) in the same sense as humans. Instead, we should focus on the ways and degree to which different phyla compare along more precise dimensions associated with associative learning. Although a complete treatment of how the piecemeal approach can be integrated with an approach like that proposed by Starzack & Gray (2021) must wait for another day, we can see the outlines of how the debate over whether plant behaviour qualifies for, say, associative learning, might shift to a multidimensional model.[14]

A final worry is that the piecemeal approach has changed the subject from our original concern for whether and how ‘plant cognition’ is genuinely cognitive. The proponent of the RDC can happily grant that many interesting questions about the similarities between plants and genuinely cognitive systems can be asked but insist that this is not the issue at stake; the issue is whether plants are genuinely cognitive. Correspondingly, the proponent of the RDC might worry that the piecemeal approach is philosophically trivial because it is only concerned with empirical questions that are neutral towards philosophical positions on the nature of cognition. Two responses are in order. First, the piecemeal approach is significant in demonstrating precisely that assessing the relationship between ‘plant cognition’ and cognition in ordinary cases can be approached without appealing to a core, essence, or mark of cognition. The claim is not *just* that we can determine in a piecemeal fashion what features typical of cognition plants possess and their degrees of similarities to animals but that, at least in one sense, such questions provide the means for addressing the cognitive status of plants. In other words, what is cognitive about ‘plant cognition’ is to be answered, at least in one sense, by discovering the extent of their cognitive features, as defined above. Admittedly, the piecemeal approach is philosophically bolder when combined with an explicitly no-core view which states there is no core, essence or mark of cognition, and so perhaps *all* there is to addressing plant cognitive status is answering questions about kinds and degrees of similarities between plants and paradigmatic cases. However, given the logical independence of the piecemeal approach and the no-core view, and to be maximally concessional, my strategy has been to remain neutral as to whether cognition ultimately possesses a core, mark or essence.

Second, philosophically trivial or not, the piecemeal approach underscores a point that has received insufficient attention: much existing debate over plant cognition depends on perpetual disputes between frameworks like cognitivism and enactivism where, in this context, cognition is often assumed to possess a core, mark or essence. Whether cognition should be seen this way is disputed by no-core views but here is the rub: even if, say, the RDC is successful and plants are denied bona fide cognitive status once-and-for-all, many interesting questions remain about the relationship between genuine cognition and whatever it is plants do.

With everything that has been said, it is worth asking ourselves what the allure of attributing cognition to plants is. As we saw in §2, discussions of plant cognition typically begin with plant scientists or philosophers observing a range of abilities and underlying mechanisms associated with cognition and here we find a clue. In keeping with the piecemeal approach, the question ‘are plants cognitive?’ is not necessarily to be interpreted as an ontological sorting exercise for determining what ultimate categories plants belong to. It can also be interpreted as a guiding heuristic for scientific research. By thinking of plants as cognitive creatures—by viewing them through a ‘cognitive lens’ or from a ‘cognitive stance’—our attention is drawn to the

[14] One way to understand the relative ease of establishing that some species is capable of associative learning versus causal cognition, theory of mind, mental time travel etc., is that associative learning is characterised by fewer dimensions, so recognising its presence of absence depends less ambiguously on similarity judgements.

search for associated abilities (like learning) and typical processes or mechanisms (like action potentials). For example, it was arguably viewing plants through a cognitive lens that afforded the productive search by Gagliano et al (2016) for associative learning behaviour. Or it could be argued that ongoing work on decision-making in plant foraging is aided by attention to cognitive-like, intelligent behaviour (Trewavas, 2014). Finally, it was perhaps considering plants from a cognitive perspective that facilitated the recent call to search for analogous roles in learning for dopamine in mice and plants (Calvo, 2022). In short, viewing plants from a cognitive stance is a useful heuristic for guiding research into concrete capacities or behaviours and their underlying causes.

§6. Conclusion

Mounting evidence suggests that plants exhibit a number of capacities or behaviours associated with cognition and share many processes and mechanisms underpinning cognition in creatures with nervous systems. However, demarcating cognition on representational grounds may exclude plants, regardless of how sophisticated their capacities or behaviours might be because they lack the appropriate sorts of representational processes. However, one might doubt the value of a representation-based characterisation if persuaded by non-representational theories of even human cognition. Such post-cognitivist possibilities point to an impasse over the question of plant cognition due to fundamental disagreements over how to conceptualise the nature of cognition. Nevertheless, I set out an alternative approach to addressing the cognitive status of plants—or what is cognitive about ‘plant cognition’—which does not depend on the success of any particular view on the fundamental nature of cognition. The piecemeal approach sets aside whether cognition has a core, mark or essence, and instead focuses on a set of concrete questions regarding which ‘cognitive features’ plants possess i.e., the particular capacities or behaviours exhibited by plants (such as associated learning), their underlying processes or mechanisms (such as neurotransmitters) and the degree of similarity between these and paradigmatic cases of cognition. The result is not a totalising picture resulting from the dichotomous question of whether plants belong to the same cognitive kind or category as humans and other animals but a nuanced and multidimensional view of how different taxa compare in their manifestation of features associated with cognition.

Ultimately, the primary value of viewing plants through a cognitive lens may lie less in settling ontological questions about which taxa are members of the official cognitive club, and more in its aiding the empirical search for concrete capacities or behaviours and their underlying causes.

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