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## *What Is It Like to Be a Plant?*

**Abstract:** *In this article, I explore the possibility of plant subjective awareness within the conceptual framework of Plant Neurobiology — an emerging discipline that aims to unearth the way plants perceive and act purposefully. I shall argue that plants lack none of the functional structures that are supposedly needed, and so we have no scientific reason to exclude the possibility that they have evolved different structures that underlie their own subjective experiences.*

Where you tend a rose, my lad,  
A thistle cannot grow.

— Frances Hodgson Burnett (1911), *The Secret Garden*

### 1. Introduction

In the opening paragraph of his seminal ‘What Is It Like to Be a Bat?’, Thomas Nagel (1974) warned us that the problem of consciousness didn’t belong to the same category as, for example, the oak tree–hydrocarbon problem. The latter has to do with more or less successful episodes of reductive explanation in the history of science. As plant biochemistry and plant cellular and molecular biology continue making headway, we have an increasing understanding of the details of the substrate, of the carbon compounds that an oak tree, so to speak, reduces to. But consciousness is a whole different business; it’s a *truly* thorny issue.

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Plants can be thorny too, and by this I don't mean that some of them can bear thorns! This paper is not about botany, but about the very possibility of plant consciousness. The last decade witnessed the birth of a new discipline, *Plant Neurobiology* (see Calvo, 2016), whose target is plant signalling and adaptive behaviour. The objective, ultimately, is to account for plant intelligence beyond the limits of basic plant science under plant biochemistry or plant cellular and molecular biology. Overall, plant neurobiology aims to unearth the way plants perceive and act. It is in this setting that I wish to pose the following question: 'What is it like to be a plant?' In my view, the time is ripe to at least cast the problem in a scientifically tractable manner.

Nagel didn't choose bats for no special reason. And neither have I with respect to plants. In his case, the choice of a mammal was motivated with an eye to somehow ease resistance. After all, of those who think human animals are not the one and only species capable of reflection, most probably would be thinking of non-human mammals as potential candidates. Bats are mammals and thus, in principle, appear to fit the bill. But, in so far as they are sufficiently awkward as told from our own experiential standpoint, bats also serve Nagel's 'intuition pump' purpose, to borrow Dennett's (1991) term. Our sensory apparatus and theirs, let us put it, are not that similar; to the point that, somewhat tongue in cheek, Nagel comments: 'anyone who has spent some time in an enclosed space with an excited bat knows what it is to encounter a fundamentally *alien* form of life' (Nagel, 1974, p. 438). Well, bats, however alien they may look, still are mammals. Let me tell you something: if there are aliens around us, these are plants!

On the other hand, we may agree with Nagel that consciousness spreads pretty widely. Plausibly it is not one of those things only mammals *do*, but 'widely' doesn't mean it happens indiscriminately all over the place. Some forms of life may have it, some others not. In Nagel's view, 'It occurs at many levels of animal life, though we cannot be sure of its presence in the simpler organisms' (*ibid.*, p. 436). One thing is for sure: if plants happen to have conscious experiences in one form or another, then there must be something it is like to be a plant.

Some caveats are in order before further ado. Nagel does not specify what he means by 'simpler organisms'. Plants and animals are both multicellular eukaryotes, and from a phylogenetic point of view none would qualify as 'simple'. It is possible that he has in mind prokaryotic single-celled life forms. One way or another, his 'levels of

animal life' phrasing excludes plants, regardless of their complexity. On the other hand, there are hundreds of thousands of living green plant species. Thus, to draw the parallel more precisely, the proper question to be posed should be: 'What is it like to be a rose?' (or a thistle, for that matter!). Of course, were panpsychism to be correct, then all green plants, being so *high* up the phylogenetic chain, would uncontroversially be minded. But my main thesis does not rest upon the truth of panpsychism, however strong the arguments in its favour may turn out to be. In what follows, I shall ignore subtleties along these lines for ease of exposition, although we should bear in mind that some plant species might well have evolved consciousness, whereas others may have not. Last, a word on terminology. Despite the emphasis on 'consciousness', the ensuing discussion is to be understood in a wider context in so far as various aspects of mentality, including subjective experience, awareness, inner representation, central coordination, goal-directedness, memory, self-awareness, and qualia are discussed. These concepts may be clustered separately as qualitative and intentional aspects of mentality, respectively. This article is primarily about qualitative aspects of the experiences of plants, although in order to elaborate on such subjective character, intentional aspects will be incorporated into the discussion as we proceed. Let us first step down the tree of life in our quest for other forms of experiencing the world, and see what invertebrates are up to, in order to pave the way for a better understanding of plant life.

## 2. Of Insects, Nematodes, and Cnidaria

Barron and Klein (2016) have recently tracked consciousness down the animal phylogenetic tree. According to them, the origin of consciousness in its simplest form probably dates back to the Cambrian explosion, a period that brought land vertebrates in between 542 and 488 million years ago. But as the fossil record shows, most of the animal phyla, not just vertebrates, appeared during this, geologically speaking, brief lapse of time. In fact, Barron and Klein move beyond mammals and vertebrates, and consider subjective experience in insects:

The brain structures that support subjective experience in vertebrates and insects are very different from each other, but in both cases they are basal to each clade. Hence we propose the origins of subjective experience can be traced to the Cambrian. (*ibid.*, p. 4900)

Colonizing the land must have brought about different selective pressures, and it is not unlikely that new predation relations gave a ‘little’ push to evolutionarily more sophisticated solutions to those of pre-Cambrian life forms. Of course, land vertebrates were not the only ones needing to get used to their new environment. Invertebrates also came out of the Cambrian period with their own needs, evolving their own toolkits. But ‘invertebrate’ is a vast category selection. They are estimated to make up some 95% of all animal species found on Earth. We may thus narrow down our search and pick from insects, nematodes, cnidaria, annelids, arachnids, crustaceans, mollusks, and a large etcetera. Some of these may have evolved a sense of awareness, and others not. Barron and Klein circumscribe their quest to insects. One way or another, a borderline is to be marked. As expected, plants are out of the game even before the ball has started to roll — ‘However, consciousness also gives out somewhere. Plants do not have it. It would be surprising if jellyfish did’ (*ibid.*, p. 4900). As a philosopher of plant neurobiology, I’m used to plants being neglected in the cognitive science literature (Calvo, Martin and Symons, 2014; Calvo, Raja and Lee, 2017; Calvo, Baluška and Sims, 2016), but we’ll get to that soon. First, what is it exactly that makes insects good candidates, and jellyfish bad ones?<sup>1</sup>

It goes without saying that, when it comes to insects and jellyfish, introspective or verbal reports are of little help. Behavioural studies, by contrast, may help, but have problems of their own. For one thing, the less similar a species is with respect to us (non-mammalians?), the more difficult it is to interpret their behaviour. Bluntly, it seems easier to infer that my dog is happy from his tail wagging (although for some surprises, see Quaranta, Siniscalchi and Vallortigara, 2007) than to infer an analogous pattern in the case of an insect. In any case, the risk of anthropomorphizing the very way we think of experiments and our interpretations always lurks in the background. We seem to project our preconceptions into the very experimental setting being designed. In a sense we constrain our subjects to act as they are expected to from our point of view (examples of artificial lab settings abound). On the other hand, when we look at the neural correlates of consciousness (Metzinger, 2000), rather than at overt behavioural

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<sup>1</sup> For contrast with Barron and Klein (2016), see Tye (2000) who argues that although honeybees may well be conscious it is unclear that the same holds when it comes to other insects.

manifestations, we are subject to a related type of mammalian bias: we cannot help it but search for the neural correlates of subjective phenomena, at least in part, in the neocortex. Maybe, we can throw a distinctive light by looking at insect neuroethology (Huber and Markl, 1983), and that is what Barron and Klein (2016) have done.

Searching the neuronal bases of natural behaviour provides the opportunity to correlate the behaviour of insects and neural activity. We have thus at our disposal an approach, both comparative and evolutionary, that can do away with the biases of mainstream behavioural and cognitive neuroscience. By paying attention to the underlying mechanisms of insect natural behaviour, Barron and Klein aim to throw light upon their alleged subjective experience. To this end, they endorse Merker's (2007) working hypothesis, according to which mammalian basic awareness correlates with midbrain areas, and not with the cerebral cortex, the latter serving full-blown self-reflective thought. The midbrain appears to suffice to create inner representations of the surrounding environment. These states, in so far as they are both integrated and egocentric, Barren and Klein contend, allow for subjective experience to take place. In the case of insects, structures functionally similar to the midbrains of vertebrates, specifically the cephalic ganglion, can serve an analogous role. Their claim is thus twofold: first, integrated and egocentric representations of the surroundings of vertebrates are located in their midbrains; and second, the cephalic ganglion of insects is the functionally similar neural structure that permits us to ponder the question of insect consciousness scientifically.

Barren and Klein (2016) elaborate on Merker's insight on cortex-less consciousness in vertebrates with an eye to paving the way for expanding the proposal to insects. What seems to be crucial in this context is that vertebrates and insects are able to organize their natural behaviours in a non-reactive manner by exploiting an integrated model of the environment. Vertebrates use their midbrains to combine information from exogenous and endogenous sources alike, producing a unified overall adaptive response; and insects perform the same elaborate, non-reactive responses by other means. One way or another, insects appear to be able to access the spatio-temporal structure of their local environment by means of free and reversible bodily movement enabled by various sensorimotor organizations that act as globally organized cohering units, and not collections of individual stimulus-response relations (Calvo and Keijzer, 2011). For current purposes, we may grant the framework as applied to vertebrates and

insects, and focus on what it is that nematodes and cnidaria appear to lack. In the next two sections, then, I shall argue that plants lack none of the functionally similar structures that are supposed to be needed, and that it is not nonsensical to wonder what it might be like to be a plant.

Consider cnidaria first, in particular *Tripedalia cystophora*, a species of box jellyfish. *Tripedalia cystophora* can exhibit rather sophisticated behaviours. It guides itself visually courtesy of a rather complex arrangement of different types of eyes, some of them camera-type ones, others mere pinholes, foraging by sinking and spreading its tentacles to hunt prey. Obstacle-avoidance is also part of its repertoire, being able to detect roots, for instance, and manoeuvring accordingly (Garm *et al.*, 2007). Despite their impressive achievements, Barron and Klein remind us, control is an illusion. Under the microscope, *Tripedalia cystophora* boils down to a fully decentralized box of gadgets. Different subsystems implement a number of stimulus–response operations, but no command centre, however tiny, is to be found. No one is at the wheel, so to speak. If a degree of centralization is a prerequisite for subjective experience, and I shall concede Barron and Klein’s point for present purposes (although see Silberstein and Chemero, 2011), it seems that cnidaria does not qualify.

But don’t think that any living organism whatsoever that enjoys some degree of neural centralization escapes the fate of being a *zombie*. If centralization is needed, it is not enough. Nematodes exemplify this other type of unhappy ends. In this case, *Caenorhabditis elegans* is the model organism Barron and Klein have chosen to drive their point home. *C. elegans* does have a centralized nervous system (in fact, their simplicity has made of *C. elegans* an ideal model organism) that permits the integration of information from a variety of sources, both exogenous and endogenous. Moreover, flexible behaviour by this nematode is known to take place (both habituation — Rankin, Beck and Chiba, 1990 — and classical associative conditioning — Wen *et al.*, 1997 — have been reported). But despite having a well-studied centralized nervous system that allows for their impressive success, it seems that anything beyond their immediate surroundings eludes *C. elegans*. When entering starvation mode, they exit an environment with dietary restrictions, widening the scope of an otherwise random search for food (Lüersen *et al.*, 2014). If they happen to succeed it is because locomotion pays off in their local environment, but no *anticipation* or *goal-directed* behaviour

appears to be taking place. *C. elegans*, we may say, is unable to go beyond the here-and-now.

Could plants possibly escape the cruel twist of fate of nematodes and cnidaria? In the remainder of this paper I shall introduce the unfamiliar reader to the plant neurobiology literature, and argue that some plants may have subjective experiences, if insects do, all according to the aforementioned considerations.

### 3. Of Plants

Consciousness, we may concur, probably dates back to the Cambrian explosion. But if the alleged structures that support subjective experience are basal to vertebrate and insect clades, tracing back the emergence of subjectivity to the Cambrian allows other actors to enter the scene. The Cambrian explosion in the evolution of land animals (542–488 million years ago) has a parallel in the evolution of land plants (circa 400 million years ago). In fact, the root-shoot/leaf polar morphology of higher plants was pretty much settled during the Devonian period; the same period in which land colonization was accomplished by vertebrates and arthropods. Plants should at least be given an opportunity, if only to cancel their conscious status, as has been done with nematodes and cnidaria. In the aforementioned situation, to pave the way for insect consciousness, Barron and Klein complained that:

[T]he bias toward clever animals is itself distorting. Many invertebrates live comparatively simple lives, without complex forms of communication and social behavior. If one cares about the basic capacity for consciousness and where it came from, one should be prepared to accept that the origins of consciousness may lie in animals that do only very boring, unclever things. (2016, p. 4900)

We may disagree doubly: the origins of subjective experience may well lie in so-called ‘lower’ animals and plants alike, and both of them may well be doing very clever things indeed. Interestingly, the idea that plants are boring and unclever is pretty extended and represents the traditional view of plant intelligence in philosophy and cognitive science. Patricia Churchland, for example, observes:

If you root yourself in the ground, you can afford to be stupid. But if you move, you must have mechanisms for moving, and mechanisms to ensure that the movement is not utterly arbitrary and independent of what is going on outside. (1986, p. 13)

This is pretty much in line with what Barron and Klein think of *C. elegans*. And in her *Brain-wise: Studies in Neurophilosophy*, Churchland insists:

First and foremost, animals are in the moving business; they feed, flee, fight, and reproduce by moving their body parts in accord with bodily needs. This modus vivendi is strikingly different from that of plants, which take life as it comes. (2002, p. 70)

Again we may disagree with these statements doubly. For one thing, labelling some phenomenon as boring or not depends on our means of observation. Bluntly, watching grass grow may not be that boring if you make use of time-lapse photography. But, more importantly, time-lapse has allowed us to do away with the ‘couch potato’ understanding of plant life, permitting plant researchers to notice non-programmed forms of movement that may make us doubt that plants are stupid at all, as research on plant neurobiology is beginning to unveil. What is this thing called ‘plant neurobiology’ then?<sup>2</sup>

Succinctly, plant neurobiology (Baluška, Mancuso and Volkmann, 2006; Brenner *et al.*, 2007) aims to account for the way plants behave *purposefully*. Philosophy and cognitive science have until very recently been neglectful of the discipline, but fortunately the topic is not taboo anymore (see, for example, Trewavas’s 2014 *Plant Behaviour and Intelligence*). As it turns out, plants are able to integrate diverse sources of information; to make decisions; and may even be able to perform predictive modelling (Friston, 2005; Clark, 2016).<sup>3</sup> Basic forms of plant memory can be induced by a panoply of environmental signals, with traces lasting from a few seconds (think of a Venus flytrap shutting its trap after repeated trigger hair tapping — Böhm *et al.*, 2016), to days or weeks (think of *Mimosa pudica*’s leaf-folding behaviour in response to repeated stimulation — Gagliano *et al.*, 2014), and even years (think of cases of ‘priming’ against pest resistance — Trewavas, 2009). Basic forms of individual learning throughout ontogeny, and not just sensory adaptation at the evolutionary scale, have also being reported. As a matter of fact, that plants can be habituated has been known for over a century, at least since the

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<sup>2</sup> A response to Churchland (1986; 2002) is elaborated further in Calvo, Martin and Symons (2014). For a *Philosophy of Plant Neurobiology* manifesto, see Calvo (2016).

<sup>3</sup> Predictive modelling can take place unconsciously (see Hohwy, 2012), and I shall ignore it for present purposes. For experimental tests of predictive processing applied to plants, see Calvo, Baluška and Sims (2016), and Calvo and Friston (2017).



pioneering work on *Mimosa pudica*, first of Pfeffer's (1873), who reported how their leaflets would close no longer after repeated stimulation, and later with Bose (1906).

Of course, with their eye-opening responses, Venus flytrap and *Mimosa pudica* are the examples that first come to mind. But these cases won't serve our purpose for at least two reasons. First, if the evidence to be considered is robust enough and cuts across plant species, plant neurobiology cannot rely on a couple of flashy, but rare, illustrations (even if gathered in natural settings to avoid conflict with the neuroethological approach herewith endorsed). But even if the behaviour of the more trendy plants could be exported across phyla, we saw in the previous section that *C. elegans* was precisely raised as an example of centralized neural processing in a model organism able to perform associative learning (like *Mimosa pudica*; see Gagliano *et al.*, 2014), but that would not pass the cut for consciousness. It appears then at first sight that plants have failed on two counts: like jellyfish, they lack a centralized nervous system; and like *C. elegans*, they are anchored to the here-and-now, failing to exhibit anticipatory, goal-directed behaviour. In what follows I shall argue that this diagnosis is faulty on both fronts. To see why, we shall consider, first, the neural-like side of plant life, and second, a particular illustration of navigation and anticipatory, goal-directed plant behaviour.

Consider first the alleged lack of neural centralization; well, even worse, consider the very lack of neurons! By now, and taking into account that plants simply don't have neurons, the careful and the not so careful reader will have found the very name of the discipline — plant neurobiology — somewhat distressing, to say the least.<sup>4</sup> For starters, and to ease tension out, note that electrical events can propagate in the membranes of neural and non-neural cells alike. In fact, electric signalling constitutes a widespread form of communication. Just take action potentials. Plants fire spikes of voltage too, and action potentials (APs) play a central role in integrating the plant body.<sup>5</sup> The study of 'sensitive' plants brought to the forefront the urge to consider

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<sup>4</sup> For reasons of space, I can only refer the reader to Calvo (2016) for a more thorough justification of the terminology and etymology. See also Calvo, Sahi and Trewavas (forthcoming).

<sup>5</sup> A review of plant APs can be found in Pickard (1973) — see also Baluška and Mancuso (2009) and Volkov (2006). In addition, another type of long-distance signalling, known as slow wave potentials (SWPs) or variation potentials (Trebacz, Dziubinska and Krol, 2006), exists in plants.

the possibility that APs, akin to animal ones, underlay their adaptive responses. However, this was not confined to *Mimosa* or *Dionaea*. ‘Ordinary’ plants fire too (Gunar and Sinykhin, 1962; 1963). As it turns out, electric signalling is found virtually everywhere in the plant kingdom. In fact, plants respond electrically to many different environmental factors. Light, gravity, touch, sudden changes in temperature, water resources, salt stress, and many other sources can trigger an electrical response, allowing plants to switch on, for instance, turgor regulation for the sake of coordinating organ movement. Overall, cellular electric excitability underlies the ability of plants to respond in a fast and yet coordinated manner to environmental contingencies.

As in the case of animal APs, ion channels mediate the generation of APs in plants. It is noteworthy that APs, animal and plant alike, are an all-or-nothing affair. That is, the amplitude and shape of the AP won’t change once a threshold is reached, however strongly we increase stimulation. Self-propagation at a constant velocity and amplitude does provide a reliable medium of communication. As to the transmission of the electric signals, in the case of animals they propagate rapidly along the nervous system, some muscles, and glandular cells. Plant excitable cells lack axons or, for that matter, any other cellular projection tailored for the conduction of electric impulses. However, plant APs don’t differ that much from those recorded on animal heart or epithelium cells. In the case of plants, propagation of waves of depolarization across plant cells over long distances take place along the phloem.

Suffice it to say then for present purposes that the similarities between plant and animal cells are noticeable, and that cellular electrical excitability for the purpose of the transmission of information relies upon the capacity of plant cells to conduct signals from receptor to effector sites, despite the lack of a central nervous system proper (Baluška, 2010). If this is so, and granting that invertebrate research paid off in so far as in relevant functional respects insects were enough like vertebrates, then plants should not be discarded beforehand. A central nervous system is not needed for plant communication and coordination to take place. We may thus move on to our second hurdle: the here-and-now of nematodes (and of plants?).

Plants navigate many vectors, not just light and gravity; vectors whose integration is critical and accounts for the adaptive responses observed. Flexible behaviour requires coordination among the diverse

plant structures. This calls for the integration of information signalling across the root and shoot systems to achieve the plants' overall goals (Trewavas, 2005). Intercellular signal integration is implemented at the electrical level via long-distance electrical signalling.<sup>6</sup> It is the degree of flexibility (phenotypic, morphological, and physiological) that can be observed in the behavioural repertoire of plants as they assess, say, potential conditions under pressure (Trewavas, 2014) that licenses our quest for plant consciousness.

We were demanding nematodes anticipate the future, and not simply to respond to present environmental conditions on a one-to-one basis. Plants are able to do just that, anticipate the future. Consider resource allocation to roots. Plants appear to be able to anticipate competition for resources, growing differentially depending upon the future acquisition of minerals and water (Novoplansky, 2016). In a set of experiments with *Pisum sativum* (pea) plants (Shemesh *et al.*, 2010), different roots belonging to the same plant were exposed to different nutrient regimes. Crucially, if roots were given the possibility to choose the conditions in which to grow, they would develop greater biomasses in patches perceived as having an increasing nutrient level, rather than a higher but not increasing one. As Novoplansky (2016) reports, this research shows that plants are sensitive to relative values of resource availability, and not to absolute values *per se*. The capacity to perceive the spatial and temporal gradient trajectories of resources (*ibid.*) and to integrate such information underlies the manifest capacity of pea plants to anticipate favourable conditions to grow in a contingent environment where resources are patchily distributed and can change dramatically. Many other examples of anticipatory behaviour exist but, for present purposes, resource allocation at the root level will suffice.

Recall from Section 2 that *C. elegans* had a central nervous system able to integrate information, and yet the ascription of consciousness was called into question. It seems that the reason was the possibility that these nematodes evolved occupying rather stable niches in which sophisticated anticipatory behaviour was not really needed after all. However plausible that is in the case of nematodes (and I shall not

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<sup>6</sup> Of course, integration critically depends on the chemical and molecular levels, thanks to the production of certain neurotransmitter-like chemicals, and the transport of auxin as well as other phytohormones (Brenner *et al.*, 2007). We focus on electric signalling for the sake of drawing the neural/non-neural parallel more vividly.

press here further, but see Calvo and Baluška, 2015), we can see that plant roots may not be put in the same basket. The soil environment in which roots make their living is anything but static/discrete. Just think of the decomposition of organic matter, competition for resources, droughts, and a large etcetera. Soil structure is patchy and changes dynamically. It seems then that some information processing machinery is needed if roots are to prosper in such uncertain terrains (Hodge, 2009). Bluntly, very simple behavioural control systems of the sort Barron and Klein (2016) envisage in the case of nematodes are clearly insufficient.

These considerations point to the possibility that, functionally speaking, and despite lacking a central nervous system, plants are not unlike hungry insects that navigate their way to food sources. In the case of insects, it goes without saying, homeostatic needs must be taken into consideration (the state the insect is in, as an agent, its memory traces and learning profile, are relevant). Insects do not merely respond to the here-and-now in a one-to-one stimulus–response fashion. But if the goal-directed behaviour of insects is the result of the internal exploitation of the spatial and temporal modelling of their local environment, the same may be said of plants. For one thing, plants are able to sample and integrate in real time many different biotic and abiotic parameters, not only nutrient patches and micro-organisms in the soil, but of course humidity, light, gravity, temperature, and many more. Plants also exhibit self-recognition and territoriality (Schenk, Callaway and Mahall, 1999), being able to tell apart own from alien, and exhibiting goal-directed behaviour (Gruntman and Novoplansky, 2004). Some plant roots can map spatially the local soil with barriers and inanimate objects included, targets to grow away from before contact has been established (Falik *et al.*, 2005). In addition, a very sophisticated sensorimotor system that includes proprioception (Bastien *et al.*, 2013; Dumais, 2013), with sensory information being transduced via a number of modalities, is found in plants (Trewavas, 2009; Baluška and Mancuso, 2013). Such integrated structures, I contend, may well support their capacity for subjective experience, or at least it is a possibility worth exploring.

#### 4. What Is It Like to Be a Plant?

How truly widespread is consciousness across the tree of life? Do plants have a point of view of their own? Of course, in order to picture what it is like to be a plant it is of little help to imagine yourself all

dressed up in leaves photosynthesizing, or stretching your arms out and twisting your body in impossible postures, pretending to be a trunk with branches. The question is not what would my experience be like were I to *behave* like a plant. The truly vexing issue is rather what it is like *for the plant* to be a plant. It is the subjective character that we're after. We must put ourselves in the plant's shoes, or, I should say, in the plant's *roots*, if you'll forgive the pun. How are we to proceed then? Winding back to the beginning of the discussion, the context of Nagel's original challenge may provide some hints.

In 'What Is It Like to Be a Bat?', Nagel wasn't simply warning us not to mistake the problem of consciousness with the more tractable problem of reduction in the natural sciences. Nagel was targeting the belief that mental phenomena are within the scope of the explanatory richness of reducing disciplines. Whichever parcel defies reductive explanation belongs to the realm of the philosophically emergent. In the case of bats and echolocation, emergentism applies to the phenomenological features of their experiences as displayed by echolocating sensations. Plainly, we shall never be able to empathize with them, to picture their subjective point of view, whatever it is like, Nagel claimed. In the case of plants, I believe it is possible, at least in principle, to frame their point of view in terms of plant neurobiology. In a sense, as I shall try to show, being able at all to envisage what it is like to be a plant, or a bat, has a lot to do with how much we know about the neurobiology of plants, or bats, and the way that, as agents, they interact with their local environment.<sup>7</sup>

The response that Paul Churchland gave when discussion of Nagel's work was in its heyday in the 80s may furnish us with some clues as to how to proceed as we move from bats to even more alien creatures! In 'Reduction, Qualia, and the Direct Introspection of Brain States', Churchland (1985) argued that a matured neuroscience may well have the resources to accommodate our subjective experience. Among other cases, Churchland pondered on the skills of the sommelier whose perceptual capacities, transcending those of the lay, call for a very special terminology appropriately tailored to the need of describing the richness of the perceived flavours and aromas of the

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<sup>7</sup> It goes without saying that I'm not anywhere near the core of the 'hard problem of consciousness' (Chalmers, 1995) — the very existence of subjectivity — but that is not the target of this paper. For a recent attempt to tackle the hard problem, see Silberstein (2015).

wine being tasted. What is it like to be a wine taster? A professional wine taster has acquired a very particular set of skills. In her case, she will easily discriminate between tannin, ethanol, glycol, fructose, sucrose, all the way to up to twenty or more different elements. Another favoured example of Churchland, the familiar reader will recall, had to do with differing discriminatory auditory skills of a child as opposed to those of the grown-up symphony director that she has turned into. There is no question that the skills of the adult conductor, like the ones of the adult sommelier, have suffered a drastic transformation from childhood; a transformation deep enough to allow them to *imagine* beyond what we might be initially willing to accept.

Interestingly, and before we can fully appreciate the reach of Churchland's insights, it is worth noting that plants are not that different from sommeliers; they have their *nose* too! Many plants can sense their own odours as well as the odours of plants in their vicinity. Among other chemicals, plants emit and detect ethylene, setting an airborne communication channel that signals, for example, ripening (Chamovitz, 2012). Some plants, like *Cuscuta pentagona* (dodder), lacking the means to make their own food (they have no chlorophyll to absorb sunlight and synthesize carbohydrates), evolved a parasitic lifestyle, sucking nutrients out of the vascular system of the hosts they twine round. To do so, they rely on volatile cues. In the case of the human sommelier, her nose is receiving many different airborne chemicals all mixed up to furnish the bouquet of the *Rioja* wine she is tasting right now. Her trained brain processes all that information coming from the receptors in her nose that travels up her olfactory nerves. We know from Section 3 that the lack of olfactory nerves in itself is not an issue, in so far as other means for electrochemical communication are available. In the case of our plant *sommelier*, not only can they sniff juicy victims to suck nutrients from, but their capacity to discriminate is truly remarkable. They've been observed to grow toward both tomato plants and wheat plants, but can tell tomato and wheat volatiles apart (Runyon, Mescher and De Moraes, 2006), showing a preference for the former, as one of the chemicals that contributed to the latter's bouquet contains a repellent. Of course, we know that in the case of fellow humans olfactory receptors have direct connection with the more ancient limbic system where emotions find their neural correlate. It is not impossible that dodders find themselves *repelled* by some potential hosts, and *attracted* by others.

In pretty much the same way that some invertebrates may have evolved consciousness and others not, we mentioned at the outset that,

whereas some plant species might well have evolved consciousness, others may have not. We may thus wonder not what it is like to be a plant, but rather what it is like to be *Cuscuta pentagona*. We saw that navigation was important in ascribing mental life to insects. Climbing plants happen to be on the move all day long. A parasitic climbing plant perspective on the world will have to do with their interests. And if there's one thing they are interested in, it is hosts to climb onto and suck nutrients from. The way dodders navigate their local environment has been revealed courtesy of time-lapse photography.<sup>8</sup> Generally speaking, revolving movements of nutation (circumnutation) in plants are due to differential cell growth, and therefore are irreversible (plant stems grow alternatively on different sides, which results in the stem bending in one direction, then in the opposite one). In addition, circumnutation of the stem is not exclusively triggered by external forces themselves, but is rather brought about, maintained, and modified by endogenous means, or at least that is a working hypothesis (see Calvo, Raja and Lee, 2017). Plants explore, and exploration uses up energy and therefore needs to be done efficiently, especially considering that growth-related movements are irreversible. Control thus appears to be needed for the regular pattern of bending observed as dodders approach their hosts to obtain. In particular, both the direction and the amplitude of nutational movements require control, if the metabolic cost of irreversible but idle movements is to be minimized.<sup>9</sup>

The navigation skills of dodders are goal-directed. They've been observed to perform an ordinary movement of circumnutation in the early stages of development, and as they grow and approach their target the pattern of nutation changes. The sophistication of modified circumnutation is something that Darwin himself had already noticed, more generally. In a description of the circumnutation of *Ceropegia*, Darwin observed:

When a tall stick was placed so as to arrest the lower and rigid internodes of the *Ceropegia*, at the distance at first of 15 and then of 21 inches from the centre of revolution, the straight shoot slowly and gradually slid up the stick, so as to become more and more highly inclined, but did not pass over the summit. Then, after an interval

<sup>8</sup> A video, limited though to US & Territories, can be watched at: <http://www.pbs.org/wnet/nature/what-plants-talk-about-video-dodder-vine-sniffs-out-its-prey/8234>.

<sup>9</sup> For a mathematical analysis of the guidance of circumnutation of climbing bean stems, see Calvo, Raja and Lee. (2017).

sufficient to have allowed of a semi-revolution, the shoot suddenly bounded from the stick and fell over to the opposite side or point of the compass, and reassumed its previous slight inclination. It now recommenced revolving in its usual course, so that after a semi-revolution it again came into contact with the stick, again slid up it, and again bounded from it and fell over to the opposite side. (Darwin, 1875, pp. 12–13)

Now, couldn't we possibly learn to apprehend mental life in a special manner once a matured neuroscience has been adopted? That was the suggestion Churchland made when it came to introspecting our own brain states, or the states of fellow humans and other animals. And it is my suggestion in the case of plants.<sup>10</sup> In trying to imagine what the experiences of a plant would be like, we're a bit in the position, not of contemplating Nagel's bat, but rather of Jackson's (1982) Mary, the neuroscientist that knew everything there was to be known about colour, but just had not experienced it, having spent all her life in a black and white room. Once having mastered all of plant neurobiology, would we still be missing some information that proves crucial to our capacity to put ourselves in the shoes of a plant?

Well, this depends on what we mean by 'all of plant neurobiology'. It can be a lot! As with Mary's potential of imagination (Churchland, 1985), we may be surprised by how radically our plant neurobiology conceptual framework could change, and how deep our capacity to introspect could go. We may imagine how plant neurobiology information could provide us more and more details about the alleged qualia aspects of the sensations of our plant. Very gradually, we could train ourselves to conceptualize the inner life of *Cuscuta* in terms of a complete plant neurobiology, yet to come. In the very same way that Churchland asked us to imagine Mary's sensations, not as 'a sensation-of-black' (or of grey or of white), but as spiking frequencies in the occipital cortex writ large, we may, aided by the appropriate plant neurobiology toolkit, imagine being in the non-neural yet spiking frequency states of the plant (recall that plants were not alien to electrophysiology and action potentials).

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<sup>10</sup> I suspect this is something Darwin would not have disagreed with, judging by how the passage quoted continues in Darwin's text: 'This movement of the shoot had a very odd appearance, as if it were disgusted with its failure but was resolved to try again' (Darwin, 1875, pp. 12–13). Although I have my opinion, I do not wish to enter into exegesis as to whether Darwin actually meant 'as if' scientifically or metaphorically.



Of course, I'm not saying it is easy to put yourself in the shoes of a plant. In fact, in pretty much the same way that, from an evolutionary perspective, non-human vertebrates, despite agreeing they are conscious, need not be conscious in the way we are (they have their own sense of awareness), plants may have evolved their own sense of awareness too; a form of subjective experience tailored to their needs and doings. That we may not be able to picture it only points to a limitation of ours, not to a handicap of them. Plants detect information in their environment that we are blind to, in pretty much the same way that we cannot detect odours the way a dog or a plant does.

To repeat, I am not saying that asking the reader to picture a parasitic plant searching for prey is not a long shot. But if we proceed step by step, it's less outlandish that you may think. In the same way that the fact of not being able to have the experiences of another person, say a blind person, does not prevent you from granting that she has a point of view, we may remove barriers with respect to other species with some extra effort. We could first imagine a blind person relying on sonar cues for the sake of obstacle-avoidance. In fact, like bats, some blind people can echolocate, using tongue-clicks to navigate their surroundings. Nagel speculated from this case:

Perhaps if one knew what that was like, one could by extension imagine roughly what it was like to possess the much more refined sonar of a bat. The distance between oneself and other persons and other species can fall anywhere on a continuum. (Nagel, 1974, p. 442)

The interspecies *continuum* here is the key. We thus must picture the natural behaviour of our preferred model organism in the context of a natural selection continuum, and move on from the more to the less familiar. Are we thereby granted the capacity to extrapolate all the way 'down' from our own case to the inner life of a plant simply by exploiting such a continuum? Certainly not. We may very well end up realizing that, regardless of the amount of information that a complete plant neurobiology gathers, we simply cannot picture what it is like. But this would not tell against the sense of awareness of plants, but only reveals our limitations to empathy, and relatedly, of introspection. To accomplish it in some cases, and not in others, may only point towards shared neural/computational mechanisms between the target organism and us. That may be one of the reasons we feel it easier to imagine the subjective experiences of mammals than that of insects, for instance.

But think again of the fellow dodders. I cannot help but see them in tandem with locked-in syndrome human patients; cases of genuine mental life, but where an almost completely paralysed body, except for a blink appropriately wired-up to some software puts them in contact with the external world. Were it not for the software, they may be completely unable to share their world with us. We may take them for zombies, devoid of a subjective experiential life! We may be making the same mistake with regard to plants. Our climbing friend may well be richly experiencing the world as it effortfully tries to latch onto its host, and yet we may take it for a zombie. In the case of the dodder, it is not the inability to communicate, but the lack of understanding of their inner doings until we open a window to their wonderful world, in this case thanks to time-lapse photography. The plant, before we time-lapsed it, resembled pretty much a locked-in syndrome patient that cannot blink and flag that she is mentally alive.

### 5. Conclusion

In this paper I have explored the possibility of plant subjective awareness within the conceptual framework of plant neurobiology. There is nothing esoteric about it. In fact, we may even wonder whether plants can feel pleasure or pain. Could stress in plants be accompanied by pain (Calvo, Sahi and Trewavas, forthcoming)? Of course there is a lengthy philosophical history of plant sentience, that stretches all the way back to Plato and Aristotle who stated that plants have souls, of the appetitive or desirous variety (Timaeus 77b), and that plants have a nutritive soul (De anima 411b27), respectively. Leibniz wrote, ‘I do not dare assert that plants have no soul, life, or substantial form’ (1687/1989, p. 82) — see also his (1690/1989). In his *Man, A Plant* (1748), La Mettrie noted many similarities between humans and plants, suggesting that plants have minds, if only ‘infinitely smaller’ than the human. Many other philosophical authors have covered related aspects (see Marder, 2014). These are topics that have until now simply been neglected by the scientific community. It’s always struck me as bizarre that, when it comes to mental life, we align plants with stones and machines, and not with living organisms. We don’t give it much thought. That’s what they are. *Matter*. We are mind, they are matter. Consistent with the *status quo*, but not with plant consciousness (or even insect consciousness), *The Cambridge Declaration on Consciousness* proclaimed back in 2012:

The absence of a neocortex does not appear to preclude an organism from experiencing affective states. Convergent evidence indicates that non-human animals have the neuroanatomical, neurochemical, and neurophysiological substrates of conscious states along with the capacity to exhibit intentional behaviors. Consequently, the weight of evidence indicates that humans are not unique in possessing the neurological substrates that generate consciousness. Nonhuman animals, including all mammals and birds, and many other creatures, including octopuses, also possess these neurological substrates.<sup>11</sup>

If the main thesis of this paper is on the right track, the backlash against anthropomorphizing consciousness is truly far-reaching. Neither brain size nor having a neocortex appear to be needed. Despite the manifest powers of imagination of we humans, the group of basic, cognitive, and computational neuroscientists that somewhat solemnly undersigned this declaration may not have foreseen four years ago that the declaration might be in need of revision so soon after launch; a path that without opening other cans of ethical worms was initiated by the Swiss *Federal Ethics Committee on Non-Human Biotechnology* (ECNH), whose report issued in 2008 ('The dignity of living beings with regard to plants: Moral consideration of plants for their own sake') constitutes a clear declaration of intent.<sup>12</sup>

Maybe the term 'consciousness' carries far too much baggage but, for the 'phylogenesis trick' to work, we're talking about mere awareness. If the central ganglion of insects plays the functional role of the mammalian midbrain in so far as the sensing and feeling of the local environment is concerned, we have no scientific reason to exclude on non-empirical grounds the possibility that other forms of life have evolved different structures that underlie their own subjective experiences (Calvo, Sahi and Trewavas, 2017). By considering the experiences of plants we may obtain a more embracing picture of the evolution of consciousness. Consciousness may well have evolved multiple times across evolutionary history. If the evolution of subjective experience is a sound topic of research, then we cannot discard the possibility that consciousness has evolved across evolutionary time quite independently a number of times. Awareness may unite us with the rest of animals, and, maybe, why not, with the bulk of living organisms, and we only need to approach it scientifically, without

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<sup>11</sup> <http://fcmconference.org/img/CambridgeDeclarationOnConsciousness.pdf>.

<sup>12</sup> [www.ekah.admin.ch/en/documentation/publications/index.html](http://www.ekah.admin.ch/en/documentation/publications/index.html).

prejudices, giving ourselves a wonderful opportunity to embrace a more encompassing notion of consciousness.

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