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Multiple ways to implement and infer sentience

Commentary on **Segundo-Ortiz & Calvo** on *Plant Sentience*

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Abstract: Segundo-Ortin & Calvo's (S&C's) thorough review of "plant neurobiology" presents evidence supporting the possibility of plant sentience. They make a compelling case that plants anticipate, assess risk, cooperate, mimic, and pursue goals, as do their animal counterparts. S&C point out that there is a double standard: behavioural patterns associated with subjective experiences in humans are considered valid for inferring cognition in non-human animals but not in diverse other systems including plants. We argue that cognitive functions, including sentience, can potentially be achieved by very different systems and their disparate substrates. We offer some context from the basal cognition literature and suggest that the deep insights of neurobiology have relevance far beyond neurons.

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1. Whether in plants or animals, cognitive functions such as sentience are always inferred. Segundo-Ortin & Calvo (2023) (S&C) dispel the twin myths that (a) plants are merely reflexive organisms, and that (b) sentience or *felt states* (i.e., the capacity to experience as a subject) are only accessible to, or likely to be experienced by, animals. Regarding (a), S&C report mounting empirical counterevidence. Regarding (b), they make the case that current objections to the possibility of plant sentience are based on intuition and unsupported reasoning. They point out that cognitive scientists have become increasingly willing to attribute sentience to members of the animal kingdom despite our longstanding inability to measure subjective experience directly in any species (including humans). Indeed, all attributions of cognition (i.e., mental actions), including sentience, are always inferred on the basis of embodied behaviours, including verbal self-report in humans. If felt states in humans and other animals are always inferred, why is the same leap from observable behaviour to inferred sentience not afforded to other organisms, including plants?

S&C approach the question of plant sentience by demonstrating that their behaviours are fundamentally cognitive because they are goal-directed, anticipatory, flexible, and adaptive. These qualities are fundamentally unlike simple reflexes, which are comparatively rigid, typically inborn, and do not require any accompanying mental action. As S&C point out, plants can integrate chemical, electrical, optical, and mechanical signals to discriminate kin from non-kin and they can compete or cooperate with neighbouring organisms. These interactions are predicted by hierarchical rule sets that change according to physiological needs. Plants also display context-dependent habituation responses, learn to avoid otherwise neutral stimuli by paired association (classical conditioning), re-orient themselves in anticipation of reinforcements, and evaluate risk to inform game-theoretic decision-making. Most impressively, plants engage in mimicry to avoid predation and can even exploit the perceptual biases of animals within a single lifecycle.

Although none of these behaviours (or any behaviours) necessarily require sentience, they are often proposed as evidence of animal sentience because of their subjective correlates in humans. When humans are observed to cooperate or compete with each other, imitate the actions of others, outwit predators, or re-orient their bodies in anticipation of rewards or punishments, cognitive scientists are willing to consider the possibility of an accompanying subjective experience. This is consistent with the common intuition that other people are "minded" (i.e., they have a theory of mind; Premack & Woodruff, 1978), which is often extended to non-human animals without significant controversy. As S&C suggest, the same willingness to attribute sentience to animals by analogy must be afforded to plants. That animal sentience is inferred on the basis of some likeness to humans is ultimately an intuition.

To be consistent, in the absence of uniquely tuned properties afforded to a narrow kind of cellular substrate, the same charitable interpretation must be extended to all systems that display observable response patterns that are consistent with animal cognition, including artificial intelligences, metaplastic materials (Loeffler et al., 2023), and robotic systems (Clawson and Levin, 2022). If behaviour is the window to sentience, evaluation criteria must focus on observable response patterns without reference to the means by which they are produced. Indeed, a system-agnostic approach offers the best roadmap for a deep, empirically fruitful unification of frameworks across cybernetics, behavioural science, bioengineering, robotics, materials science, and biomedicine (Davies and Levin, 2022; Levin, 2022; Mathews et al., 2023; Rosenblueth et al., 1943).

2. Other cognitive functions can be implemented by very different substrates – why not sentience? If, as S&C suggest, plants are potentially sentient, how do they achieve felt states without nervous tissue and a brain-like centralized processor? S&C point out that, like animals, plants synthesize and signal with several common neurotransmitters, including the amino acid glutamate, the most abundant excitatory neurotransmitter in the human central nervous system (Brosnan and Brosnan, 2013). Plants also display action-potential-like depolarizations which propagate along distributed vascular networks of aqueous conduits. Whereas plants and animals share a surprising degree of overlapping electrochemical physiology, their anatomical organizations are quite different.

Relevant here are the concepts of multiple realizability (Bickle, 2006) and substrate independence (Bostrom, 2003). Multiple realizability refers to the idea that the same function can be implemented by very different systems. Similarly, a function is said to be substrate-independent when it can be achieved without the contingency of a particular material or physical medium. Computation, for example, can be implemented in many ways by machines and living organisms alike. It is quite possible that *felt states* can be achieved in multiple ways

and by many different biological substrates – a hypothesis that is already seriously considered when discussing the possibility of sentience in animals that are sufficiently different from humans. It is already a mainstream assumption that cognitive functions, including memory, attention, and perception, are similarly realized by disparate brain structures across species. Despite differences in cortical lamination, minicolumn dimensions, cell density, and gyrification, it is generally assumed that sentience is, at minimum, *possible* in non-human animals. Many neuroscientists subscribe to the concept of biological degeneracy (Mason, 2015), identifying structurally dissimilar regions within brains that can achieve the same functional outcomes (e.g., blindsight responses mediated by subcortical and brainstem nuclei, with independent, duplicate maps of retinal inputs; Cowey, 2015).

If different organizations of nervous tissue can achieve the same functions, the possibility that cognitive capacities, including sentience, can be achieved by other tissues should be considered. It is highly implausible that all sentient life in the universe achieves felt states using the neural circuitry underlying human consciousness on earth. Plant sentience is likely to be the tip of the iceberg of sentient systems yet unknown (Ramstead et al., 2019).

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