Article

Sentience Everywhere: Complexity Theory, Panpsychism & the Role of Sentience in Self-Organization of the Universe

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ABSTRACT

Philosophical understandings of consciousness divide into emergentist positions (when the universe is sufficiently organized and complex it gives rise to consciousness) vs. panpsychism (consciousness pervades the universe). A leading emergentist position derives from autopoietic theory of Maturana and Varela: to be alive is to have cognition, one component of which is sentience. Here, reflecting autopoietic theory, we define sentience as: sensing of the surrounding environment, complex processing of information that has been sensed, (i.e. processing mechanisms defined by characteristics of a complex system), and generation of a response. Further, complexity theory, points to all aspects of the universe comprising "systems of systems." Bringing these themes together, we find that sentience is not limited to the living, but present throughout existence. Thus, a complexity approach shifts autopoietic theory from an emergentist to a panpsychist position and shows that sentience must be inherent in all structures of existence across all levels of scale.

Key Words: sentience, complexity theory, panpsychism, self-organization, Universe, autopoiesis.

Introduction

Two philosophical approaches to understanding the nature of consciousness in the universe predominate: *panpsychism* in which consciousness is conceived as pervading the universe at all levels, and *emergentism* in which consciousness is understood to arise from the universe when the universe becomes sufficiently complex (and organized in such a way) to produce it (Seager & Allen-Hermanson, 2010). Of course, each of these categories subdivides into still more nuanced versions and perspectives. Where emergentism is concerned, particularly, there is the obvious stance that it is the nervous system, or perhaps the brain in particular, that represents the complexity and organization necessary to create consciousness; however, other perspectives suggest that it is not the brain per se, or even nervous systems in general that are required, but that life in its most basic form, i.e. the cell, is sufficient and necessary for rudimentary forms of

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consciousness.

This latter view was principally proposed by Francisco Varela and Humberto Maturana in their formulation of the concepts of *autopoiesis* (Maturan & Varela, 1973; Varela, & Rosch, 1991), then further developed through collaborations of Varela and other colleagues, in particular Evan Thompson (Varela, Thompson & Rosch, 1991; Thompson, 2004; Thompson, 2007). In their famous view, where there is life, there is mind, mind being expressed through the embodied activities of an autonomously active, autopoietic unit, whether that unit is as simple as a cell or as complex as creatures with central nervous systems such as humans and other primates, elephants, dolphins, whales, etc.

This emergentist perspective immediately calls to mind the terminology of complexity theory, in which *emergence* specifically refers to properties and structures that arise, bottom-up, from the self-organization of interacting members of a complex system (rather than through top-down planning and design) (O'Connor & Wong, 2012; Lewin, 1999; Johnson, 2001). Indeed, the two uses of the term are sometimes similar. Thus, some emergentist positions take complexity theory itself into account, suggesting that consciousness is a macro-scale emergent phenomenon arising from the interacting neuronal networks of the (central) nervous system at a lower level of scale (O'Connor & Wong, 2012).

However, in general, when applied to the philosophical question of consciousness the word emergence is used with less precision than when it is used as a technical term in complexity studies. One should therefore be cautioned in concluding that a complexity theory perspective on consciousness necessarily supports the emergentist point of view. It is our position that, in fact, a careful application of complexity principles to analysis of self-organization across all levels of scale – down to the smallest, Planck scale of existence (approximately 10^{-35} meters) – suggests that at least some simple elements of consciousness are found wherever there is existence.

These elements we will specify as "sentience" and, for the purposes of our discussion, below, sentience is here preliminarily defined as: 1. sensing of the surrounding environment, 2. complex processing of the information derived from what is sensed, (i.e. via mechanisms of processing that fulfill the criteria of a complex inclusive of limited randomness or *quenched disorder*) (Theise, 2004; Theise & D'Inverno, 2004; Theise, 2006), and 3. generation of a response. These activities and the elements or structures that mediate them will be further defined, below, as the discussion proceeds. Our analysis will then proceed to consider how complexity theory actually points away from an emergentist perspective toward a panpsychist position: "sentience everywhere." We note that sentience does not imply self-consciousness, which may be confined to higher species. Self-consciousness implies sentience but not necessarily the other way around.

Brains Only?

That the brain produces consciousness appears, simplistically, as an elegant solution to the problem of the origin of consciousness. Given its enormous complexity and the apparent association of brain topography and activation with discrete mind states and functions, this is virtually self-evident to most of our scientific and popular culture. However, the simplicity of that solution starts to dissolve when one considers the brain from an evolutionary point of view. It is not as though brains suddenly popped into existence prepared to produce mind, after all. Evolutionary biologists approach the question meaningfully by looking for simpler structures from which brains evolved, recognizing that in lower order living beings there are neuronal structures that, while not as complex as our brains, perform less complex but similar versions of the functions of consciousness (Miller, 2009). Some of these are central nervous systems, but some of them are disseminated through the body rather than being concentrated in a "central" location. For example, the worm-like Sacoglossus kowalevskii (Pani, 2012) has aggregated functional clusters of cells as in the vertebrate nervous system, but well defined anatomic structures as in vertebrates is absent. In the sea anemone Nematostella vectensis, the entire endoderm and ectoderm has neurogenic potential, but the nervous system per se they have a more diffuse, "nerve net" comprised of cells identifiable as neurons or, at least, having similar functioning as nerves (Nakanishi, 2012). Thus, a gradual development toward central nervous systems - perhaps over parallel, but independent evolutionary paths – derives from pre-existing, more dispersed nervous system elements (Miller, 2009).

These evolutionary paths can be traced backwards not only into less densely aggregated and less complexly organized nervous systems, but the components of neurons themselves predate the evolution of neurons and thus functional aspects of nervous system-like activity predate the rise of neurons. As in all evolutionary development, the pieces often precede the structures that eventually arise with new functions, not by creating new structures, but by reorganizing existent structures in novel fashion. Thus, the specialized cellular structures that we commonly deem essential to neuronal signaling, the ionic channels that conduct electrical signals along the neuron and the synaptic structures that convey signals between cells, are found as independent entities in simpler life forms (Miller, 2009; Meech, 2008). In particular, the ionic channels in cell membranes (e.g. calcium, sodium, potassium channels) are found in virtually all cells. Thus, some of the simplest elements of nervous systems that support or even create the complex elements of consciousness are present throughout the evolutionary tree, no matter how simple the organisms are, down to the single cell level. Could these simpler structures, not yet evolved into complex nervous systems, give rise to simpler forms of consciousness? It is precisely this question, when broached by Maturana and Varela, that yielded the equation "mind = life".

Autopoiesis and sentience

Autopoiesis, as initially presented by Maturana and Varela (Maturana & Varela, 1973; Varela, Thompson & Rosch, 1991; Thompson, 2004; Thompson, 2007), can be considered a variant of a complexity theory, self-organizational approach (though Maturana, himself, disagreed with this alignment [Maturana, 1987]). The word derives from the greek: αυτο- meaning "self" and –ποίησις meaning "creation", thus (Maturana & Varela, 1973):

> An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i)

> through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network.

Initially presented as a way to define living systems, it specified the criteria that pointed to cells as the smallest possible unit of life. But it also accomplished more than this. The autopoietic approach specifies four characteristics of autopoietic systems, inclusive of all single cell organisms, that serve to define the essential, minimum form of mind, namely sentience that leads to "sense making" (Maturana & Varela, 1973; Varela, Thompson & Rosch, 1991; Thompson, 2004; Thompson, 2007). So, for example (one at which we will look at more closely), a paramecium swims along increasing gradients of nutrients like sugar, but will reverse direction in response to toxic gradients or obstructions to movement. Thus, the organism senses the environment and responds to it by changing behavior. In doing so, it also assigns "value" to aspects of the environment, thus "making sense" of it: nutrients are "good", toxins and obstructions are "bad."

One may immediately object that by such a definition an environment sensing air conditioner is sentient and sense making: it will turn off when a room is "too cold" and turn on when the room is "too warm", seeking to regulate to regulate room temperature to accommodate Goldilocks' "just right." The sense making aspect for an air conditioner, however, does not arise from the unit itself, but is defined from outside the system by the person who decides the set points. Thus it seems that biological autonomy (Grandpierre and Kafatos, 2012) is of fundamental importance here. The apparent sentience of the air conditioner is thus not the same as that of the autopoietic unit. The air conditioner simply has an on/off switch that responds to temperature sensors. The unit's behavior is therefore simple, mechanical, and completely predictable in every detail; it never varies. It does not have an internal processing of information performed in a complex manner.

The living system, on the other hand, senses and processes the perceived information about the environment in a complex, non-mechanical, not completely predictable way; as with all complex systems, there needs to be an element of low level randomness or "quenched disorder" in the system which allows for variant responses and, therefore, the potential for adaptation if the surrounding environment changes. For the mechanical, non-autopoietic machine, it is, in part, the inflexibility of response that leaves an air conditioner without the capacity to autonomously adapt. The air conditioner, unlike a living, autopoietic unit, cannot evolve.

Let us look at the paramecium more closely. They swim, in a corkscrew movement by beating the tiny, hair-like cilia that cover their surfaces in unison, like oarsmen moving a boat forward. When a paramecium encounters a physical obstacle, it backs up, changes direction, and tries to move forward again. As a single cell, it can't have a nervous system, let alone a brain. How does it "know" it has hit an obstacle let alone determine how to respond "appropriately" by backing up and changing direction?

When the cell membrane encounters the obstruction, the membrane deforms, leading to a conformational change in small molecular channels in the flattened part of the membrane that, in turn, causes membrane depolarization that elicits an action potential leading in turn to ciliary reversal and increased beat frequency (Tamm, 1994; Pech, 1995). So the paramecium backs up. Then, the system resets and the paramecium resumes swimming forward again. This is the kind of sentience, of "mind", that autopoietic theory points to in the most minimal life unit, the cell.

In analyzing such behaviors Maturana and Varela described these four features of all autopoietic, living system (Maturana & Varela, 1973):

a. A <u>boundary</u> (the cell membrane in this example) that is open to energy, but closed to foreign materials, i.e. is semi-porous. This is boundary defines the "being" of the system;
b. The <u>processes</u> of sensing and reacting are the "doing" of the system;
c. A <u>nervous system</u> that connects external events and the internal processes of the living system in which information sensed is then processed, yielding a response;
d. <u>Communication channels</u> between the living system and its external environment (in this case, ion channels).

This description fits nicely with the evolutionary view of nervous system development and serves as a platform to understand the evolutionary development of mind that precisely parallels the evolutionary development of all living systems. It also sets a lower limit on where one may find consciousness or, in this more limited, simple framework at the single cell level, of sentience. The cell is the smallest unit that satisfies the criteria for an autopoietic system. No simpler system exists and, thus, one may say that autopoiesis/life is where one finds mind and where one does not find life, one would not find mind understood in these terms.

Complexity in autopoiesis

Complexity theory can provide some important supplemental perspectives to this autopoietic analysis. First, there is the simple question of how atoms and molecules can self assemble into autopoietic units. This has been described elsewhere in greater detail and relates to the general features of complex systems (Lewin, 1999; Johnson, 2001; Theise, 2004; Theise & D'Inverno, 2004; Theise, 2006). To highlight: independent of scale, the self-organization of interacting elements into larger scale, emergent structures is potentiated by when they display four sets of characteristics:

a. There must be sufficiently large numbers of interacting agents. How great the complexity of self-organization relates to how large the numbers are (there are clearly sufficiently enormous numbers of interacting atoms and molecules that comprise a living cell).
b. There is an overall balance of homeostatic, negative feedback loops governing the interactions between agents (within cells biomolecules generally interact through homeostatic feedbacks). Positive feedback loops may be present, but cannot predominate
c. There is no global sensing of the condition of the system. For example, no molecule is "aware of itself" as part of the larger process, but instead is simply responding to Brownian motion resulting from the thermal jostling of the aqueous

substrate in which it floats and to various physiochemical interactions with other atoms/molecules of the cell. Likewise, no cell is observing the tissue or organism as a whole, they merely respond to cues from the local environment.

d. There must be limited randomness (often referred to as "quenched disorder") in the system. Too little disorder would prevent exploration of new states of self-organization to adapt to a changing environment. Too much disorder would prevent self-organization. In the cell, Brownian motion provides the energy of physiology and movement between biomolecules comprising molecular motors; energy conveyed by dissociation of molecules such as ATP serves to quench this disorder into functional molecular activities (Yanagida, Iwaki & Ishii, 2008; Ishii Y, 2008; von Delius & Leigh, 2011).

With this framework we can see that the internal processing of information that results in a response to a sensed environment necessarily incorporates quenched disorder, thus opening the door, for example, to autopoietic "doing" that allows for adaptation and evolution, as noted above. This further specifies the difference between internal information processing of a programmable machine and a truly living system. In this way, a complexity approach is supportive and even clarifying of some aspects of the autopoietic analysis.

On the other hand, however, complexity theory also undermines the nature of the autopoietic unit as something particularly distinct from the lower level structures beneath it. It does so in that another key aspect of complex systems is that their features are *scalable*, meaning that the general principles apply throughout different levels of scale. Thus, while we may consider atoms and molecules as self-assembling (when in aqueous solution at appropriate temperatures) into cells, cells, in turn, fulfill the same criteria and can thereby self-organize into communities of cells (i.e. "bodies" as diverse as bacterial colonies, occasionally more actively coordinated structures like slime molds, and true multicellular organisms). Moving upwards in scales, these bodies (however selected for observation or study) can interact forming structures as diverse as ant colonies, flocks of birds, cities, cultures, economic markets, ecosystems (Lewin, 1999; Johnson, 2001; Theise, 2004; Theise & D'Inverno, 2004; Theise, 2006).

Likewise, moving downward in scale, while cells arise from self-organizing molecules (Theise, 2005), molecules in turn arise from self-organizing atoms (with quenched disorder now being supplied by quantum mechanical processes), atoms themselves arise from self-organizing subatomic particles, and so on, down to the Planck scale where the smallest entities ("strings" or otherwise) do not arise from anything smaller, but appear and disappear from the energetic vacuum in a "quantum foam" (Figure 1). These principles have also been explored elsewhere in greater detail (Theise, 2004; Theise & D'Inverno, 2004; Theise, 2005; Theise, 2006; Kurakin, 2004, Kurakin, 2005; Kurakin, 2006), but serve to point out the specified complexity of the autopoietic unit is merely one type of complex self-organization, but is not particularly special as such. In this light, this "lower boundary" of living systems at the single cell level may not be the lower boundary of sentience, per se. Therefore, another view is suggested.

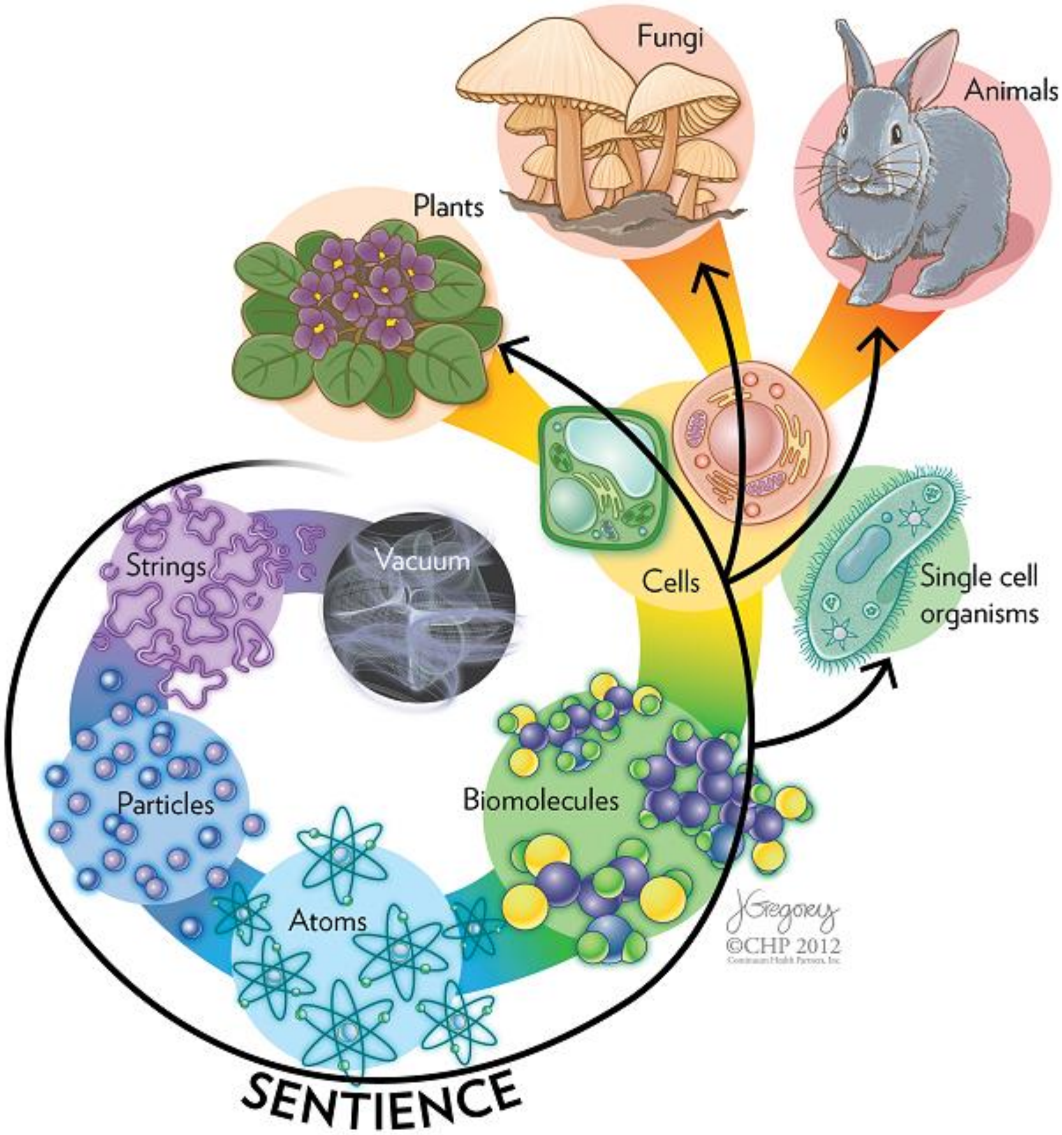

Figure 1. The universe as self-organizing, complex "systems of systems" in which sentience is identifiable at all levels of scale from the quantum foam up through living (autopoietic) beings.

Mediating elements of "nervous system" signaling

In all the examples of nervous system functioning considered above, it is electrical and ionic flux that conveys the response to sensed information from the environment. Nerve action potentials signal through changing ionic flux generated by coordinated opening and closing of ion channels, in a more complicated version of that seen in the single cell example of the paramecium. Can a similar kind of information processing and signaling be found in structures at scales below the level of the smallest autopoietic unit, such as in some biomolecules? Indeed they can.

One example serves to clearly define this possibility. The structure of the DNA double helix is highly conductive, the electrons of the DNA base pairs dissociating and traveling as an electrical current through the helix. The structure of the helix creates "electron holes", however, where there is no electrical flow (Barnett et al, 2001; Giese, 2006). Moreover these \ electron holes are most prominent over coding regions of the genome and will trap ionizing, potentially mutating radiation entering the helix and then transfer the potentially mutating energy to a non-coding region of the genome. In these areas, mutations are less likely to result in injury to the cell/organism. Thus, we have a biomolecular example in which there is sensing of the environment, complex internal information processing (with quenched disorder supplied by quantum mechanical effects), and a subsequent response to what has been sensed. Indeed, there is even a hint of sense making in that the shift of ionizing radiation is protective against crippling mutations to the coding regions of the genome. Other examples may include molecules of import to some contemporary hypotheses regarding consciousness itself and the nature of quantum behaviors in biomolecules within nerves and nervous systems, including, of course the tubulins and their assembly into microtubules in the theories of Hameroff and Penrose (Hameroff, 2007).

Thus, at least some biomolecules display a simpler form of sentience, but sentience nonetheless as we have defined it. In turn, atoms do the same, sensing the environment and interacting with other atoms, through the electrical activities of their electron shells – atomic sentience; simpler, but still sentience. Strip away the electron shells and what happens in the nucleus? The protons and neutrons interact through exchange of small subatomic particles such as quarks, gluons, muons, etc. And these smaller subatomic particles? Onward down to the smallest entities. At these lower levels of scale, the "internal processing" is mediated by quantum effects which, necessarily, include an element of quenched disorder: the probabilistic behaviors of quantum mechanics.

But at these lowest levels of scale, from the subatomic downward, we are deep in the quantum realm where all entities are defined by wave functions that extend infinitely in all directions, overlapping with all others. Thus, technically speaking, there is no "external" to be sensed and no "internal" processing to create a response to the external; rather, the component activities that define sentience are inherent and pervasive, to be currently described, in part, by the concepts of quantum entanglement and non-locality. In the quantum realm one might tentatively suggest that the notion of "sentience" be considered a simplest form of "self-sentience", i.e. nascent self awareness. What precisely would be the differences between higher mammals and other biological organisms in terms of self awareness is an open question.

Beyond the Planck limit there is nothing smaller. There is simply the energetic vacuum, the creative void, out of which all existence arises, building itself through complex self-organization from smallest subatomic entities into larger subatomic particles into plasmas and atoms and such, thence into molecules, autopoietic living systems, worlds (Greene, 2000). Thus, a complexity perspective locates no organizational or dimensional boundary to sentient activity, merely differences in the level of complexity of that sentience and apparent and inherent self-sentience at the lowest scales in the quantum realm, those smallest entities after emergence from the vacuum. As Kafatos (2000) and Kafatos and Nadeau (2000) have argued, the universe is imbued with consciousness (in our language sentience, although we again emphasize that consciousness which includes self-consciousness is not quite the same as sentience, the latter being a much more general feature of structures in the universe) at all levels.

Table 1. Some mediators of sentient activity at different levels of scale and complexity

Sentient Entities

	Planck Level Non-locality	Gluons	Mesons	Electrons	Ions	Molecules[1]	Cells[2]	Nervous Systems[3]
Complex Multicellular Organims				+	+	+	+	+
Simple Multicellular organisms				+	+	+	+	
Single cells				+	+			
Biomolecules				+				
Atoms				+				
Hadrons			+					
Quarks	+	+						
Strings (or…)	**Entanglement**							

[1]Biomolecules, depending on the species, such as neurotransmitters, hormones, antibodies, leptins, etc.
[2] Cells belonging to the organisms (e.g. neurons, immunocytes) or microbial flora living in synergistic mutualism (e.g. gut and skin flora).
[3]Nerve nets in lower species like *Radiata*, central and/or peripheral nervous systems in *Bilatera*.

Summary and correlate concepts

Consciousness in the universe is viewed as either all pervasive (the panpsychist perspective) or arising from the universe when sufficient complexity is attained (the emergentist perspective). Emergentist perspectives may suggest that formal nervous system development is necessary for the development of consciousness, but evolutionary biologists can recognize elements of nervous systems even in the absence of cellular networks. In particular, Maturana and Varela, in their defining work regarding the self-creating/sustaining, autopoietic nature of cells identify the evolutionarily simplest forms of consciousness in single cell organisms. For many, this is a dominant emergentist view, equating the presence of life with the development of mind.

Complexity theory analysis, however, dissolves this lower boundary of life as the definitional origin of sentience, finding evolutionary aspects that will become recognizable as nervous system behavior even in the behaviors of some molecules, of atoms, of quantum level entities of all kinds. Thus, complexity theory transforms the essential features of the autopoietic, emergentist view into a panpsychist perspective.

Does this analysis mean that all things are sentient? Do sentient entities always assemble into larger scale, more complexly sentient beings? Of course they do not. Sentience is not a *material* that transfers through aggregated units, it is a *process* that may function at its most simple within larger, non-globally sentient structures. Thus, while all atoms by this analysis may be sentient and some of these may self-assemble into sentient molecules and some of these may assemble into more complexly sentient cells and multicellular organisms, they do not necessarily assemble into a sentient (to return to the earlier example) machine. The sentience harbored within the air conditioner, as a higher scale aggregate of its smaller component atoms, remains at its simple, far less complex, atomic form.

Thus, while larger scale, non-sentient entities may be defined, there is no structure in the universe that does not contain sentient entities at some lower level of scale, down to the lowest levels of the quantum realm emerging in the quantum foam. At that level, with quantum entanglement and non-locality operational for all possible units of existence (whether they are confirmed as multidimensional strings or some other structure), sentience is, in fact, universal. Moreover, given the aspects of non-locality and entanglement that pertain at these lowest levels of scale, application of concepts of "inside" and outside" become impossible; rather, all processes are internal to all interacting units and therefore we may also tentatively suggest that sentience begins as "self-sentience." It is possible that, as we would argue that higher levels of sentience relate to self-organization of lower level sentient agents, self-sentience may be related to self-awareness in more typically identified conscious beings. It is, thus, tempting to suggest that the quantum behaviors in living nervous systems, possibly mediated by microtubules as suggested by Hameroff, serve to preserve and/or conduct upwards self-sentience from the lowest levels of scale into the biological levels of scale. We may therefore ask whether our own self awareness relates to the identified self-sentience of the quantum realm.

Finally, we may also ask and perhaps answer the question: what are the minimal criteria for the smallest entities emerging from the quantum foam to be able to self-organize into the larger scale universe? Interactivity would be a baseline necessity, without which self-organization could not take place. We may, therefore, further specify that this quantum-level "sentience" is simply another way to describe the inescapable interactivity at these minimum levels of scale, without which self-organization would not follow. It is thus sentience itself – partly defined by interactivity and quenched disorder – that is the minimal criterion for self-assembly of the universe into larger scale structures, including those which are functionally adaptive (i.e. "alive"), capable of sense making and perhaps, ultimately, of being consciously self aware.

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