A Multidisciplinary Approach to Mind and Consciousness

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ABSTRACT

In the last 400 years physics has achieved great success, in theory and experimentation, determining the structure of matter and energy. The next great step in the evolution of science will be exploring the role of mind and consciousness in the universe, employing mathematics and fundamental theoretical constructs to yield specific predictions. Based on recent findings in biological autonomy, we propose to approach consciousness from the key aspect of decision-making. This approach allows us to develop a quantitative theory of consciousness as manifested in information processing. Since decision-making occurs at a certain level of organization, natural relations are obtained between consciousness at one level of organization and unconsciousness at another. By following this chain of argument, we also consider the possibility that levels of consciousness and unconsciousness form a self-closing hierarchy. This line of reasoning has led us to theoretically formulate the possible relationships between mind, cellular activity (both neuronal and non-neuronal), and the universe, working with the categories of consciousness, self-consciousness, and unconsciousness. What we propose in the present paper is a natural and straightforward extension of information theory to quantitative measures of consciousness at different levels and scales. A framework that integrates data from multiple disciplines can help us develop a broader theory of consciousness than what is possible from any single field alone. We present quantitative estimations for the rates of information processing at the global and cellular levels of the human organism and suggest values at the level of the universe. Our picture yields a new, quantitative picture of the mental capabilities of Homo sapiens and a reformulation of our place in the universe.

Key Words: genuine biological autonomy, decision making, quantitative aspects of consciousness, unconsciousness, self-consciousness, cells, universal mind

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Introduction

Consciousness is widely considered to be the greatest challenge for modern science. At present, "Not only have we so far no good theory of consciousness, we lack even a clear and uncontroversial pre-theoretical description of the presumed phenomenon" (Dennett, 1987; p.160). Historically, Samuel Butler in the nineteenth century defined sentience as being capable of making numberless tiny decisions (cited in Margulis and Sagan, 2010). In Butler's view all life, not just human life, is teleological and endowed with consciousness, memory, and direction of purpose (Butler, 1917/ 1967).

For him, amoebas have their little wants too, their little spheres of influence, their little "tool-boxes" with which they materially change their surroundings, pursue their specific goals, and build their environments. Butler argued

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that 'consciousness' (we will define such basic concepts below in the Appendix) comes first by learning how to solve problems, while 'unconscious' habits arise by applying the working solutions repeatedly in a way that does not require attention.

Recent developments in theoretical biology (Bauer 1967) and psychology (Lehrl and Fischer, 1990), along with the theory of genuine biological autonomy (by "genuine" we refer to a new type of autonomy, see Grandpierre and Kafatos, 2012; 2013) offer a new scientific context for rethinking Butler's views. It is well known that in macroscopic, non-equilibrium physical systems, the main trend, according to the second law of thermodynamics, is toward equilibration. We consider that life is basically a systematic effort to maintain and elevate itself (Bauer, 1967), or, formulating it in one word, to flourish (Bedau, 2010). In contrast to physical systems in which the main trend is approaching thermodynamic equilibrium, living organisms are organized as hierarchical systems of biological functions acting against decay. As such, we emphasize that there exist a fundamental difference between physical order created by physical self-organization and biological organization. By analogy, a living organism can be compared to a football team: A football team is not a system of players arranged in '*order*', in special spatio-temporal patterns; instead, it is *organized* in a way that all the players are endowed with special tasks to perform certain functions (that are additional to their spatio-temporal coordinates), and these goal-oriented (teleological) functions are organized to serve a central idea: scoring as many goals as possible (Grandpierre, 2013). A living organism, first and foremost, teleologically *organizes* all *its functional activities* in order to secure the ultimate aim of living and flourishing. This is why, as we think; a better term for living beings is 'organisms' rather than 'systems'.

Recently it has been argued that one of the most fundamental properties of living organisms is teleology (Grandpierre, 2012a; Toepfer, 2012). Yet the very concept of teleology seems to be exiled from modern science, since goal-orientation and purpose, apparently, do not fit the prevalent idea that the most fundamental ingredients of physical theories are physical laws formulated in terms of deterministic differential equations. Such equations appear to be incompatible with any teleology expressing an end-point "selection". Therefore, the first fundamental difficulty to be removed in building an exact theoretical biology is a conceptual one, namely, to resolve this incompatibility between deterministic physical equations and genuine biological teleology. We suggest approaching the issue with the help of the first principles of science, which are, arguably, deeper entities beyond physical or, in general, natural laws.

In physics all the fundamental equations can be derived from the least action principle. The dimension of 'action' is energy*time. Generally, the action takes different values for different paths. The least action principle selects the path between a given initial point A and a given endpoint B that minimizes the 'action'. The least action principle is the most powerful tool of physics. To obtain a similarly powerful principle for biology, one can generalize the least action principle so that it becomes compatible with life's ultimate aim of flourishing (Grandpierre, 2007). In order to do this, we have to allow that living organisms select the endpoint of their biological processes to be compatible with their biological aims. If we do so, besides the least action principle of physics we obtain the second 'first principle' of natural sciences, namely the greatest action principle in biology (i.e. what we term as the "biological principle"). Basically, the principle of greatest action expresses the fact that all living organisms strive to maximize action, actively maintaining their states as far away from thermodynamic equilibrium as possible for as long as possible: that is, to survive and flourish (Bauer, 1967; Grandpierre, 2007; Bedau, 2010). Allowing teleology to be present in biology implies that biological deviations from strict spatio-temporal physical pathways do occur.

It may seem that the greatest action principle is limited and, for example, doesn't directly apply to the case of apoptosis. Nevertheless, apoptosis generally confers biological and over long term, evolutionary advantages during an organism's life cycle. For example, the differentiation of fingers and toes in a developing human embryo occurs because cells between the fingers apoptose; the result is that the fingers and toes become separate. Unlike necrosis, apoptosis produces cell fragments called apoptotic bodies that phagocytic cells are able to engulf and quickly remove before the contents of the cell can spill out onto surrounding cells and cause damage (Alberts *et al.,* 2008, Chapter 18). The greatest action principle applies to the overall living organism, whether single cells, multicellular organisms, plants and animals. For individual cells that make up an organism, the greatest action principle does not directly apply, as the cells exist in symbiosis for the common aims and benefit of the larger organism, which they populate. Therefore apoptosis of cells is really part of the successful survival strategy of an organism.

With these terms we circumvent the problem that 'consciousness' assumes a variety of different meanings. For our purposes, we need scientifically suitable terms having less ambiguous meanings. Thus we are defining an entity as 'physical' if its behavior follows only physical laws. By comparison we are defining 'mind' as causing changes leading to deviation from physical pathways (for a more systematic definition of mind, see the Appendix). One cannot take it for granted that Nature has only a physical character. We argue that 'mind' in its full context must be a fundamental feature of Nature. The reason is that something either happens as a result of physical interactions - and so the organism follows an inertial path - or the organism actively contributes to its further development. In the second case, the organism causes systematic teleological changes (allowed by Heisenberg's uncertainty relation) leading to biological deviations from physical behavior. The organism must then decide how to deviate its path from the physical path. We propose here that genuine decisions are that fundamental and quantifiable activity of consciousness in which it manifests itself. Such decisions, by our proposal, represent the first of the two pillars connecting mind with physical matter.

The second pillar is the decision-initiated generation of virtual particles in the quantum vacuum that are responsible for eliciting subtle changes in the quantum states of a living organism (Grandpierre and Kafatos, 2012; 2013). We reserve the term 'mind' to be the general, universal entity responsible for all these systematic, teleologically organized quantum-level deviations from physical behavior as they occur anywhere in Nature ('universal mind'). According to our hypothesis, universal mind is the entity representing the potential of Nature to act on the quantum vacuum, to initiate the generation of virtual particle pairs (about the 'quantum vacuum', see Milonni, 1994). The generation of virtual particles can occur not only through the mediation of the physical principle of least action, but, in our proposal, additionally, by the biological principle of greatest action that utilizes virtual particles. This allows the determining of the possibilities that would normally be left undetermined by the physical principle alone, and it is allowed by the quantum indeterminism. In other words, virtual particles are utilized since the biological principle can act only on possibilities that are not determined by the physical principle, through the 'quantum door' that is only opened through virtual particles.

According to our proposal, genuine autonomous decision-making (Grandpierre and Kafatos, 2012) is a fundamental aspect of mind because genuine autonomous decisions are required to enable the full potential of the living organism to act for its own interests, in a continuously changing and unpredictable environment, both inner and outer. "Autonomous" refers to actions, biological and physical which are not completely pre-determined (ibid). On the human scale, even if it were shown that 95% of behavior consisted of lawful, predictable responses to situational stimuli by automatic processes, psychology could not afford to ignore the remaining 5% (Baumeister *et al.,* 1998) especially if non-automatic processes corresponding to learning are involved. All other forms of mind that we examine here below are proposed to be different aspects of the universal form (Kafatos and Nadeau, 2000; Manousakis, 2006). We argue here that even cells are not chemically predetermined machines but have a kind of consciousness, since they make genuine autonomous decisions. Our argument is as follows:

At any moment in the history of biology, biologists have vastly underestimated the sophistication of cellular mechanisms, and it is certain that we still have an enormous number of surprises ahead of us (Alberts, 2011). Nearly all cell processes are based on elegant mechanisms too intricate to predict (Alberts, 2013). As Harold (2001) noted, from the chemistry of macromolecules and the reactions they catalyze, little can be inferred regarding their articulation into physiological functions at the cellular level (ibid, 5). The crucial next challenge, thus far out of reach, is to decipher exactly how the elaborate networks of signaling molecules that exist inside a cell enable it to make its crucial decisions—a process analogous to cell "thinking" (Alberts, 2010).

We note that living organisms interact with a complex environment that is rich in unexpected changes. Therefore, even cells must continuously solve newly encountered tasks in their daily lives. Not all biological functions are pre-fixed as related to the long time scales of biological evolution. Novel biological functions are regularly acquired (Shapiro, 2011; pp.1–5 and 56), making living organisms extremely creative beings. Organisms must possess a type of intelligence if they can solve problems that no specific individual in the evolutionary history of the species has solved before (Heisenberg, 2009).

We are aware of possible objections to what we are suggesting; objections that are based on the unproven but prevalent assumption that cells are machines. This issue is still open. Yet we argue that because cells produce complex biochemical products, including molecular machines, they must be, at least, factories. Actually, no factory can be maintained without supervision or an external control. From time to time, due to decay processes like corrosion, equilibration, irregularities, and breakdowns the maintenance of machines requires both control and repair. Relegating supervision to 'higher order' machines does not help, since all machines require supervision, leading to an infinite regress.

In the last few decades, genetic essentialism, the idea of a determinate genetic program in the DNA that controls the development and functioning of the organism, rather like the digital code of a computer program, was an attractive idea. Nevertheless, recent successes in systems biology clarified that biological functionality is actually multilevel. As Noble (2008) noted, high-level functions depend on DNA and the rest of the cell. We point out that this fact makes it necessary to revise popular views about macromolecular functions, distinguishing between local, physico-chemical and biological functions at the highest, global (cellular, organismal, universal) level.

Our corresponding analysis (Grandpierre, 2013) shows that physico-chemical functions are based on local properties of biomolecules, and are merely tools of global-level biological specific functions and aims. The functions of the living organism typically depend upon the coherent operations of molecules by the millions; these involved hundreds or even thousands of different kinds, marshaled into functional organization by a hierarchy of controls (Harold, 2001; p.4). Such an organization extends over distances that are orders of magnitude larger (ibid., 66) than the individual molecules themselves. As Harold has formulated, the relation between local and global determinations in terms of what, where, when, and why: Briefly, the genes specify What; the cell as a whole directs Where and When; and at the end of the day, it is the cell that usually supplies the best answer to the question Why (Harold, 2001; p.82).

The control of 'milieu interior' is attributable to the cell or organism as a whole and it controls the lower, local level. In truth, the stretches of DNA that we now call genes do nothing on their own. Keeping that finding in mind, our point here is that in the process of cellular life, the production of biomolecules is not enough to maintain a viable cell, because the most vital ingredient is missing: suitable multilevel control securing biological organization. Besides this multilevel argument, other fundamental arguments also show that cellular organization requires a genuine autonomy of the cell (Grandpierre, 2013). It is the cell that serves as the overall supervisor of all its processes.

It is usual to consider life as defined by metabolism and reproduction. We think that life is much more than fulfilling such routine tasks. All the constant basic biological aims, together with the newly arising aims based on changes, form a dynamic hierarchy which is controlled by the ultimate biological aim of *flourishing*. This means that beyond the level of secondary aims (and their algorithmic complexity) corresponding to well-defined biological tasks, we find a deeper level of complexity organizing the non-ultimate biological aims into a coherent unit. The ultimate biological aim organizes at this deepest level of organization all the secondary aims into a hierarchical system serving the ultimate aim, to flourish. Every unit of life (cell or organism) manifests complex creative teleological activities (Grandpierre, 2008) requiring genuine decision-making to serve the aim of flourishing. Since genuine decision-making is the crucial element of consciousness, living cells must have a type of consciousness transcending chemical predetermination (cf. Theise and Kafatos, 2013).

Since high-level functioning is an inevitable teleological element of any viable cell, such cellular-level functions must be assigned to suitable biomolecules in the process of the formation of the first cell on Earth. This means that a biological factor must be present before the origin of the first cell. Based on such arguments, one of us has hypothesized that the first cell on the Earth developed from a universal, comprehensive life form having a kind of consciousness that assigns global-level functions to biomolecules transforming the first protocell into the first cell on Earth (Grandpierre, 2013).

Decision-making is level related - it occurs at a certain organizational level of the organism. Moreover, since a decision made at one level does not occur at another level, what is conscious at a certain level of organization is unconscious at other levels. Unconsciousness is meant here as decisions occurring at other levels than the reference level. Something that is a conscious process for us as individuals (such as consulting a map or getting angry) is not a conscious process for our cells. By our definition, cells can be conscious if they are making autonomous decisions. Evidently, something decided at the cellular level (such as the coordination of an enzyme with other biomolecules) is not decided at the organismal level (where decisions occur, in the case of humans, how to move our arms, legs, eyebrows, ears, what to read, what to think etc.). Therefore, using consciousness in this relative sense, there may be a variety of consciousness types in an organism; even though consciousness itself is a fundamental trait in the universe (just as blue is a color relative to other colors, while "color" is what they all have in common).

2. Quantitative Estimations

Having offered a theoretical framework, it seems advisable to examine consciousness with quantitative data about its most immediate manifestations that are measurable activities. Our first task is to obtain a closer picture of how conscious activities in cells and organism are quantified.

A useful measurement arises from the difference between reading and perception. The processing of information that occurs through reading is much slower than the information we process by perceiving the outer world. Derived as bits processed per unit time, mental speed is operationally defined as reading rate. Estimations of mental speed (here, what we 'see' when reading particular material) are in the range of 100 bits/sec or less (Lehrl and Fischer, 1990). By comparison, the flux of information obtained through our outer senses is estimated at a much higher rate, namely around 10^9 bits/sec (Anderson *et al.,* 2005; Norretranders, 1999). Regarding the fact that we learn perception from our time in the womb onward, processing the information received from our senses corresponds to memory. This is because perception in its mature form must rely on learned patterns established as a kind of 'active memory'.

Reading, on the other hand, is regarded as 'self-conscious' since the reader can recall and report in words on the content of what he has read. The data indicate that the rate of perceptual information processing is around 7 orders of magnitude more powerful than that of our self-consciousness, with the help of which we read, understand and make decisions.

Neural processing

Our brain consists of ca. 10^{11}-10^{12} neurons, yielding a brain-averaged rate for the self-conscious information processing a rate of 10^{-9} to 10^{-10} bits/sec/neuron. Neurons of the visual system process visual information at the rate of ca. 3 bits/sec/neuron (Anderson *et al.,* 2005). The average daily intake of 2,500 calories that an adult male needs to live and work translates to the turnover of about 2.4×10^{26} molecules of ATP (Kornberg, 1989; p.65) in a day, corresponding to about 2.9×10^{21} ATP/sec. Considering that an average human body consists of about 6×10^{13} cells (Alberts *et al.,* 2008; p.1442), we obtain that 5×10^7 ATP molecules are produced per human cell per second. This means that the number of molecular reactions in an average cell must be of the order of magnitude $\sim 10^8$/sec/cell. The corresponding rate of information processing that characterizes the intrinsic activity of the cells at the molecular level is estimated to be roughly 10^8 bits/sec/cell (Grandpierre, 2008). In our recent work we have argued that this intrinsic cellular activity corresponds to cellular autonomy, and thus to decision-making, the manifestation of cellular consciousness (Grandpierre and Kafatos, 2012).

These results suggest that manifested 'cellular consciousness' (the number of cellular decisions per second) is about 20 orders of magnitude more powerful than neuron-averaged human self-consciousness. Indeed, organismal consciousness may represent only an infinitesimal fraction of our full ability to process information (Norretranders, 1999; pp.124-56). For the sake of simplicity, we have ignored brain glial activity, which we agree is substantive and could also play an important role. Thus, our numbers may underestimate the enormous amount of cellular information processing that occurs in the human brain.

Moreover, active memory includes the processing not only of perceptions but also tens of thousands of cognitive schemes (Mero, 2002). One well-developed cognitive scheme is that of a world-champion chess player. Comparing the complexity of such a cognitive scheme with the capacities of IBM's Deep Blue program that beat Russian champion Garry Kasparov (Hsu, 1999), we obtain estimation for the complexity of such a cognitive scheme as being ~10^{14} bits/sec. In principle, ten thousand such cognitive schemes (as suggested by Mero, 2002) may process 10^{18} bits/sec.

Based on these quantitative grounds, we reach the conclusion that human self-consciousness can be variously characterized by an information processing capability of ~10^2 bits/sec; perceptual consciousness as ~10^9 - 10^{18} bits/sec; organismal unconsciousness (we define organismal unconsciousness as the number of decisions occurring at the cellular and supra-organismal, or universal level) of the whole human organism as ~10^{22} bits/sec. Somewhat simplifying this, the hierarchical activity of consciousness can be compared to the activity of line workers at a company processing data and preparing it in a suitable form for higher managers to make decisions at the company level. If this is the case, it means that perceptual consciousness is not completely automatic - a significant portion can be creative, corresponding to problem solving, handling newly arising, unforeseen tasks or details, and treating them according to the rules and viewpoints of the whole human system (or company in our analogy). The quasi-automatic, mechanical or reflex-like activities can be regarded as corresponding to the tacit part of consciousness (Polanyi, 1966). We can therefore formulate the following relation:

Consciousness = self-consciousness + tacit consciousness. (1)

We note that consciousness is a dynamic entity measured in bits/sec, in close relation to short-term and long-term 'working memory' (Weiss, 1995). The capacity C of short-term, static memory (measured in bits of information) is the product of the individual mental speed (MS) of information processing (in bits/sec; Lehrl and Fischer, 1990), and the duration time D (in seconds) of information in short term working memory (Weiss, 1995). We introduce the idea that since mental speed must be related to consciousness, the duration time D of information in short term working memory must be related to the 'binding time' (BT) defined as the inverse of the frequency of the gamma waves to be responsible for binding consciousness (BF, 'binding frequency'):

$$BT = 1/BF \qquad (2)$$

Since the frequency of gamma waves playing a central role in object awareness, consciousness (Rieder *et al.,* 2011), is around BF ≈ 40 Hz, we therefore obtain from (2) that BT ≈ 1/40 sec. By our proposal, D ≈ BT, and we obtain the following equation:

$$C = A \times MS \times BT, \qquad (3)$$

where A can be regarded as a coefficient of mental skill in recalling percepts. With the numerical values MS ≈ 100 bits/sec, BT ≈ 1/40 sec, we obtain C ≈ A x 2.5 bits, a result that seems consistent with the accepted value of C ≈ 4 bits (Cowan, 2001).

Universal Information Processing

We can also estimate the upper bound of information processing in the observable part of the universe. The maximum number of bits that can fit in the materially manifested observable part of the universe can be estimated from the above by assuming, as is often done in cosmology, that the observable universe is a black hole with a surface corresponding to the Hubble radius as $I_{max} = 10^{120}$ -10^{122} bits (Davies, 2004). Similarly, Seth Lloyd (2002) computes the bits by considering the entropy (closely related to temperature through the second law of thermodynamics defining entropy), by maximizing entropy, turning all of the universe's matter into radiation and then using the blackbody radiation formula to get a temperature, thus obtaining a value of $I_{rad} = 10^{90}$ bits. If, however, gravitational fields can contribute to entropy, the total is much larger, and if the universe stores information through gravity, Lloyd (cf. Davies, 2004) obtains the higher estimate of 10^{120} bits. We note that the specific type of entropy relation to information theory, the so-called Shannon entropy (in bits), is just the number of yes/no questions needed to determine the information content in a system. Therefore, dividing it by the Hubble time ~13 x 10^9 years, ~4 x 10^{17} sec, we obtain an upper limit for the rate of information processing in the universe (I) in the range I = 2.5 x 10^{72} (lower limit, corresponding to I_{rad}) - 2.5 x 10^{104} bits/sec (upper limit, corresponding to I_{max}). These rates are much larger than the sum of all organismal rates even if we assume that every star in the universe which is capable of having planets also has life. For example, if as many as 10^{23} stars in the observable universe have planets inhabited by intelligent beings like humans here on Earth, with an upper limit of bit rates of cellular unconsciousness ~ 10^8 bits/sec, and estimating the total number of cells on the Earth as 5 x 10^{30} (Whitman *et al.*, 1998), the combined bit rate for all possible intelligent life in the universe would be ~ 5 x 10^{61} bits/sec. The organismal bit rates of all living species on hypothetical planets in the universe would be several orders of magnitude higher but still << than the lower limit estimate for the universe given above. Taking an average mass for a cell 10^{-9} g, from our previous estimation of 10^8 bits/sec/cell we obtain for the average value of information processing a rate of 10^{17} bits/sec/g. Since the observable universe contains ~ 10^{80} protons, its mass is around 10^{56} g. If all the observable universe's matter was to turn into living matter, with information processing capabilities similar to cellular rates, we would then obtain that the information processing rate of the observable universe would be ~ 10^{73} bits/sec, in remarkable agreement with the lower limit we obtained above of ~ 2.5 x 10^{72} bits/sec. These estimates offer quantitative grounds for assuming that the universe can accommodate a huge number of life forms (see also Grandpierre, 2008), much larger than what the already known, terrestrial forms of protein-based life may be containing at this point in its evolution.

One may argue that biological information needs to be meaningful, whereas the universal estimate refers to algorithmic information which is, in the absence of a meaning, assigned by a mind, inherently meaningless, and as such, the two are really different. However, no one has shown how to assign any quantification or measure to meaning. Our approach starts by the common measure of bits of information per time and does apply to *both* biological and "inert" systems. Assigning meaning requires a mind and accepted norms that this meaning applies to, and is beyond the scope of the present work.

3. Model of Relations between Consciousness at Different Levels

Our starting point, approaching consciousness from its active, decision-making aspect has important and somewhat unexpected corollaries regarding its relations to unconsciousness. We can formulate the relation between mind, consciousness and unconsciousness at any of the three basic levels of organization (cellular, organismal, and universal) as

Mind = consciousness + unconsciousness. (4)

Now if consciousness has a self-conscious (reportable) and a tacit aspect, this yields the following relation:

Mind = self-consciousness + tacit consciousness + unconsciousness. (5)

Relation (5) may be regarded as the dynamic counterpart of the relation between static entities:

Memory = short-term memory + long-term memory. (5')

We note that while (5') can be measured in bits, (5) is measured in bits/sec.

Moreover, since unconsciousness is also a dynamic aspect of mind, measured in bits/sec, and unconsciousness at a certain level is consciousness at some other levels, we obtain the general relation:

Unconsciousness = sub-consciousness + supra-consciousness. (6)

This means that, relative to a certain level of consciousness, sub-consciousness corresponds to decisions made at the lower level, while supra-consciousness corresponds to decisions made at the higher level.

More concretely, in the case of a multicellular organism, (6) yields:

Multicellular organismal unconsciousness = cellular consciousness + supra-consciousness. (7)

Applying (6) to the cellular level, we obtain the following relation:

Cellular unconsciousness = sub-cellular consciousness + supra-cellular consciousness. (8)

Since supra-cellular consciousness consists of organismal and universal consciousness, we obtain a circular system of hierarchical relations (see the Appendix). We have been positing that the universe should be viewed as a biologically autonomous being (Grandpierre, 2008; Grandpierre and Kafatos, 2012). In a certain sense, both organismal and cellular consciousness can be regarded as being independent of or beyond the Universe because of their autonomy, i.e., they can decide their activities independently. In a more general sense, of course, biological autonomy is a natural phenomenon belonging to the Universe. Therefore, universal consciousness (by which we mean that of the Universe as a whole) is accompanied by cellular and multicellular consciousness. Leaving aside its other interactions, universal consciousness forms a circular system with respect to its relations to cellular and multicellular consciousness - this is considered below.

4. Consciousness and the Universe

At this point, we can consider that all decisions occurring in the Universe are made either by universal, organismal, or cellular consciousness. Substituting (6) into (4), and using the constraint that the three levels of decisions are universal, organismal and cellular, we obtain:

Universal mind = Universal consciousness + organismal consciousness + cellular consciousness. (9)

Denoting universal mind as UM, universal consciousness as UC, organismal consciousness as OC, cellular consciousness as CC, we can write (9) in the form

UM = UC + OC + CC. (9’)

We can sum up these findings compactly in Table 1.

1	2: UM	3: OM	4: CM
UC	UC	OU	CU
OC	UU	OC	CU
CC	UU	OU	CC

Table 1. A proposed architecture of the conscious Universe. First column: there are three fundamental kinds of consciousness, UC (universal consciousness), OC (organismal consciousness) and CC (cellular consciousness). Second column: UM (universal mind) = UC + UU (universal unconsciousness due to decisions occurring at the organismal level) + UU (universal unconsciousness due to decisions made at the cellular level). Third column: OM (organismal mind) = OU (organismal unconsciousness due to decisions made at the universal level) + OC + OU (organismal unconsciousness due to decisions made at the cellular level). Fourth column: CM (cellular mind) = CU (cellular unconsciousness corresponding to the universal level) + CU (cellular unconsciousness corresponding to decisions made at the organismal level) + CC.

As Table 1 indicates, the organismal mind of an individual living being involves cellular and universal consciousness; therefore, it has a huge potential for informational content (Kafatos and Nadeau, 2000; Manousakis, 2006, Görnitz, 2011).

In physics it is generally regarded that elementary particles are not really elementary, since they are based on universal fields (Einstein and Infeld, 1938; Weinberg, 1995). Similarly, if biological decision-making occurs through the quantum-vacuum (Grandpierre and Kafatos, 2012), and the Universe as a whole can be regarded as conscious (Kafatos and Nadeau, 2000) or equivalently living (Grandpierre, 2012c), then decision-making can also occur through the autonomy of a living Universe (Grandpierre and Kafatos, 2012).

5. Conclusions

How can we conceive the physical ways through which universal mind interacts with organismal and cellular minds? At the present state of the art, this question seems to be premature. For as long as consciousness remains a fundamental problem, its scientific exploration may require that even physics can be transcended or at the very least enlarged. At present, it is generally conceded that we do not know how our minds interact with our bodies. We hope that our proposed model may offer a new perspective with the help of such powerful explanatory tools like genuine biological autonomy and the biological principle acting on the quantum vacuum.

Although we know more and more about cellular intelligence and the psychoactive actions of microbiota (Sousa *et al.,* 2008) on our brain, science does not yet have a clear picture about the interactions between organismal and cellular minds. Nevertheless, there are some indications underpinning our model. One is the fact that quantum-vacuum processes have a vast potential that, by our proposal, can be harnessed by consciousness. Moreover, the phenomenon of intuition seems to be related to cellular and universal consciousness as basic ingredients of organismal mind. In a living universe, universal consciousness can be in a similar relationship of macrocosm to microcosm that we propose between organismal consciousness and cellular consciousness. We would add that in a unified scientific outlook, as well as in the actual universe, all phenomena, laws, and first principles must eventually be interconnected.

As we have argued here, living organisms, including the human, are first of all systems of consciousness capable of making decisions. In the old scientific picture the distinguishing property of human beings is our self-consciousness, to which an outstandingly high rate and quality of information processing is attributed. In the new picture obtained here, human self-consciousness has a relatively low rate of information processing in comparison to tacit, cellular, and universal consciousness. At the same time, the human mind has an outstanding rate and quality of consciousness because self-consciousness is assisted by the even higher rate of tacit consciousness, corresponding to human knowledge (i.e., all the things we have learned and remember, assisted by the extraordinary capacity of the human neocortex).

Finally, the relation of self-consciousness to tacit consciousness corresponds to one of the general tendencies of evolution, namely, the increasing development of the brain's capacity, memory, flexibility, and learning. On the basis of our results it seems that contrary to the general view, evolution is primarily the evolution of tacit consciousness, not the information processing of self-consciousness.

6. Appendix

Since we can measure only the already manifested aspects of consciousness, i.e. as manifested in the physical/material universe, therefore all such measures refer to the *most immediate, yet already measurable, physical aspects of consciousness*.

As a first step, we consider that there are three fundamental levels of consciousness in the Universe: the universal, the cellular and the organismal (multicellular), corresponding to the three fundamental level of biological autonomy (defined as the ability of living organisms to decide about their acts themselves in a way that is not determined completely by physical or biological laws and previous conditions, Grandpierre and Kafatos, 2012), which we regard as the scientifically suitable formulation of consciousness.

We define the physically manifested aspect of *consciousness as the number of decisions made in a second by the organism* under consideration (cell, multicellular organism, or the living Universe) as a whole, as a biologically autonomous being. Consciousness is inevitably relative to the first-person perspective, and so it is different at the different but autonomous levels of an organism. For example, *organismal consciousness is defined as the number of all decisions made at the organismal level by the organism*. We define the observable aspect of self-consciousness as the number of elementary bits of information processing in a second that can be reported on by the subject. Examples for self-consciousness are reading, voluntary motions, and thinking.

We define the manifested aspects of *unconsciousness as the number of all decisions in a second in the organism, made at a different than the autonomy level of consciousness*. For example, organismal unconsciousness is defined as the number of all decisions in the organism made at the cellular or universal level.

We define the manifested aspects of *mind as the rate of all decisions made in the organism, made by consciousness or unconsciousness, summed up*.

We define the physically manifested aspects of *universal consciousness as the number of decisions made by the Universe as a whole*. In our previous paper (Grandpierre and Kafatos, 2012) we found that the Universe as a whole is biologically autonomous.

We define the manifested aspects *of universal unconsciousness as all decisions made by individual living multicellular organisms and cells*.

We define the manifested aspects of *universal mind as the rate of all decisions occurring in the Universe, made by universal consciousness and unconsciousness, summed up*.

In materialism, it is usual to consider that the universe is the sum of all matter, planets, stars, galaxies etc. In a wider horizon, *we define the Universe (including matter, life and consciousness*; to distinguish it from the material universe, we write it with a capital letter) *as the unified whole of all physical, biological and psychological phenomena, laws and first principles, together with autonomy existing at the cellular, organismal and universal level*. Identifying autonomous decision making with the most immediate, yet already physical aspect of consciousness, this definition can be formulated as:

Universe = observable phenomena + laws of Nature + first principles of Nature + all the three basic forms of consciousness. (10)

We note that observable phenomena correspond to the manifested "surface" of Nature. In comparison, laws of Nature represent a conceptually more compact and deep level of Nature having vast (infinite) explanatory power and a moderate level of algorithmic complexity (Grandpierre, 2008), while the first principles a still deeper, ultimate, creative or generic level (ibid.). Correspondingly, consciousness also has three levels. The first, manifest level of consciousness correspond to "mental phenomena" like thoughts already formed in words and sentences. The second, unmanifest level of consciousness corresponds to mental forms having a certain algorithmic complexity. The third level of consciousness is the creative or generic level, the ability to decide freely and creatively, which we can call as creative consciousness. In our proposed scheme, the three fundamental levels of consciousness forms a unified whole. Similarly, we conceive the Universe as the unified whole of phenomena, laws, principles and consciousness.

Imagining an evolutionary scheme in which the primary, unmanifested Universe (we denote it as state 1) develops to materially manifested Universe (state 2), we have the following options:

Case 1. In state 1, unmanifested Universe consists of principles, and consciousness.

The other option arises when assuming that even laws and first principles of Nature are created by universal consciousness:

Case 2. In state 1, unmanifested Universe consists of consciousness.

This option (2) in principle may allow that cellular and organismal consciousness to co-exist with universal consciousness; let us denote this case as (2a). The other option is that non-manifested, primary Universe consists of universal consciousness, and cellular as well as organismal consciousness develops later on (case 2b). In that case, in state (1) cellular and organismal consciousness does exist only potentially. We can keep in mind that unmanifested Universe has, with respect to its manifested activities, a fundamentally quantum nature, closely related to the quantum-vacuum, in which potential forms can exist which are not yet manifested in material, observable reality.

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