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Article

Quantum Physics and the Ontology of Mind

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ABSTRACT

The aim of this paper is to construct an ontology to account consistently for both the objective and subjective worlds. First, I will determine the fundamental properties of consciousness from a first-person perspective and derive from them a subjective definition of consciousness. Second, I will infer from their existence at a macroscopic level some expectations about the empirical world and show that these expectations can be identified with quantum properties of matter. This will lead to the construction of an ontology and to a physical counterpart of the former subjective definition of consciousness, which accounts for the existence of a continuum between conscious and unconscious states. Finally, I will go beyond the common objections to quantum mind to propose a simple yet suitable model of mind which explains why consciousness arises specifically inside the nervous systems of living creatures.

Key Words: quantum physics, consciousness, unconsciousness, mind, ontology, subjective, objective, matter, quantum entanglement, nervous system, chaotic system.

Introduction

The main problem faced by philosophy of consciousness is to understand how our subjectivity emerges from the objective world. Choosing between dualism and monism is not the primary question, as both face the same problems. Whether a soul is attached to our brain or emerge from it does not change fundamentally the perspective: the question is how can this happen?

The root of this problem lies in the inability of our scientific knowledge to tell us what it is to *be*. The price for building an objective representation of the world is the exclusion of the subject from this representation, as Schrödinger (1974) pointed out. Science tells us how things appear to us, not what they are. It offers clues about regularities in our empirical world, but being is something singular. Actually, every moment is singular – not that they are different from each other, but that I live them one by one, and each one is *the* moment I live.

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Being is what we could call something transcendent, beyond any possible description: no word or mathematical formula can describe something as simple as what it is to be, to feel or to act. The only way we can share our inner experience with fellow human beings is to assume that they live it as we do, that they see our colors and hear our sounds – our *qualia*. But how could we describe our colors and sounds beyond giving them a conventional name? Subjectivity is given, the base of everything else and is thus unspeakable.

Given that transcendental aspect of the first-person experience, the mind-body problem can be reformulated as follows: how is it possible that such a transcendence exists while we are simultaneously able to build an objective and efficient scientific model of reality? How is it that a subject as the object of another subject can be reducible to an objective description in terms of separated particles and physical laws and what happened to transcendence during this objectification process? Did it totally vanish?

In an attempt to answer this question, I will define consciousness and its fundamental properties from a first-person perspective. I will then attempt to infer what we can expect from an objective description of the world to be consistent with the fact that these properties exist. Next I will discuss the compatibility of these expectations with our knowledge of the physical world and especially with the fundamental aspects of it through quantum physics. I will propose an ontology in coherence with all these observations. Finally I will develop the theory of mind that directly follows from this ontology and explain briefly how, according to this theory, consciousness might arise inside the brain of living creatures.

1. The Conscious Experience

Consciousness as perception of the material world

First, I will attempt to define what it is to be conscious. I won't bother with superfluous aspects of consciousness: I am not trying to describe it extensively, but to find out what is essential to it, so let's put aside the mechanisms that are unnecessary or that are only specific patterns of a more generic property.

Memory, for example, is not essential, neither are reasoning or emotions. Even sensory perception is superfluous. Indeed all these aspects are the content of our consciousness. This content exists, but it could be of a different nature without really affecting the fact that we are conscious. What is essential to consciousness is not its content, but above all the sole ability to perceive something.

One could object that memory is something essential, because for various reasons it would be impossible to be conscious without a memory. It may be true, but I am not trying here to find the conditions for consciousness to exist, but to determine its essence, and in fact, memory may be a necessary condition of consciousness but not a property of it.

As Husserl noted, consciousness is always consciousness *of something*. There is no consciousness by itself, and even the purest imaginable conscious state can be interpreted *a minima* as consciousness of a mental state, which is still *something*. There is no reason to fundamentally distinguish between mental states and perceptions: both are objects of our awareness. From now, I will use the term "perception" in a broad sense to reference any kind of awareness.

The first fundamental property of consciousness is the ability to perceive something.

Consciousness as action on the material world

We could add that this something has a material origin, since we usually perceive the material world, or to be precise, its representation built by the brain, and it is almost certain, as confirmed by lesions and drugs, that our mental states do have a material origin inside our brains too. But it is in fact more appropriate, conversely, to define the material world as the origin of our perceptions, since they constitute the only way for us to experience its existence.

One could assert that being able to perceive something is enough to define consciousness, but this definition seems incomplete without mentioning intention. Indeed, no one lives as a spectator of his or her own life, except temporarily when in a half-conscious state. When we are really conscious, we think we have control and we think of our mind not only as the place from which we perceive the world, but also as the source of our decisions, the permanent inflection of the future with our volition. Again we can say that these decisions apply to a material content and are performed through mental representations of our acts built by our brain.

It is not obvious that free will exists, and I will not discuss that question here, but even though free will was an illusion, intention would remain a central phenomenal aspect of our consciousness we would have to deal with. Let’s consider that it exists as a hypothesis. The possibility to replace this assumption with the one that only the sensation of free will exists will still remain as an option in further discussions.

The second fundamental property of consciousness is the ability to act voluntarily on the material world – or its sensation.

The irreducibility of consciousness

Perception and action on the world seem to be very distinct properties at first sight, but they apply to the same material world, and the more we look inside our mind, the less they are distinguishable. Who could say to what extent we perceive our thoughts and to what extent we choose them?

There seems to be attention inside intention. Making a decision could be described as perceiving the idea corresponding to this decision, while moving away from our mind – or "forgetting" – concurrent ideas. There is also intention inside attention. When listening to an orchestra, I am able to focus on a specific instrument and the others will move to the background, and when I look at an ambiguous picture or at a cloud which can be interpreted as an image in different ways, I can decide which image I want to see in it. Action and perception are also, to some extent, mutually exclusive: contemplation is incompatible with doing something attentively and conversely, when I am focused on a task, I don't perceive my environment with as much attention as I usually do.

Perception and action seem to be different aspects of the same movement, which Bergson called the stream of consciousness. This movement is what being is all about: perceiving and acting at the same time, and remarkably, it is a uniquely integrated process. I am not someone else nor an aggregate of several distinct consciousnesses; I am one person, myself and only myself.

The third fundamental property of consciousness is to be one single irreducible entity mixing action and perception into the same movement.

It is important to notice that regardless of its unity, the frontiers of consciousness are not clearly defined. As John Searle (1992) noted, our attention always has a center and a background, and its exact bounds cannot be exactly defined. This is a paradox of consciousness: to be single and irreducible but at the same time not to have clear frontiers.

To counter criticism, I shall also specify that the uniqueness of our consciousness does not refer to anything like the representation of self identity, just as acting on the material world does not refer to any subsequent story-telling of our acts and motivations, which requires advanced capabilities such as memory and reasoning, but to something more spontaneous and unspeakable, something like "living the moment." Neuroscience could discover that the representation of self and the story of its actions are subject to confabulations and illusions – actually it has done this. This does not affect at all the very fundamental fact that the subject and perceiver of these illusions is experienced as single.

Consciousness and the arrow of time

Actually there is a difference of nature between perception and action. Perception is always perception of the past – we see marks from the past – whereas action is directed toward the future. This distinction leads us to a property of consciousness I have not discussed yet, because it seems too obvious to be discussed, which is that consciousness is located in the present.

But a more appropriate formulation would be: the present is the moment of my consciousness. This is indeed the only way to define the present: the moment when I am conscious. Moreover, the only way to define the past is: the direction of my perception,

including the perception of my memories, and what I cannot act on, whereas the only way to define the future is: the direction of my actions and what I cannot perceive. Following Whitehead (1920), we can consider that our present is not instantaneous but has a thickness, and just as consciousness, its frontiers are not clearly defined.

It seems to us that something like a common present exists and is shared by us, other people and our environment, and we will have to deal with that question later, but until that time, we can rely on this egocentric definition of time.

Stream of consciousness can now be defined more precisely: it is a process that transforms the immediate future into immediate past in a single integrated movement, mixing action and perception together. The flow of this stream is not under our control; we cannot stop it or make it go faster. We cannot stop being – or as Sartre said, we are condemned to be free. However, the act of being conscious is tightly related to the flow of time.

This will be the fourth fundamental property of consciousness: being a stream from the past to the future and hence defining its own present.

Now we have a complete definition of the essence of consciousness which is not limited to consciousness as we know it as human beings but corresponds to what we call being conscious in its more generic and fundamental aspects. Being conscious is perceiving and acting voluntarily on the material world in a single irreducible movement that follows the stream of time; consciousness is the starting point for defining everything else, from the material world to the stream of time itself.

2. Consciousness and Materialism

Emergence and holism

Now that we have a generic definition of consciousness, let's tackle a more difficult question: how can such an entity exist in a material world?

The first observation is that human consciousness arises only in some specific conditions, basically inside the brains of human beings. This observation leads us to the concept of emergence, which states that an entity – here, consciousness – is present in some objects at a certain level – the brains – but not in its components.

Following Mark Bedeau (1997), there are two ways of understanding emergence:

- Weak emergence, for which emergent properties are only substitutes for a more complex description, such as heat is a substitute for the kinetic energy transfer of several particles;
- Strong emergence, also referred to as holism, in which case the emergent properties somehow "appear" at a certain level without any causal explanation.

We have to reject holism, not because it is necessary non-existent, but because it is nothing more than a failure to find a naturalistic explanation for a phenomenon. Holism is arbitrary; since it implies acausality, it does not tell us why or when a property appears. As long as no other explanation is needed, I will assume that we are fully part of the material world, thus causally reducible to our material constituent, because this is the hypothesis which requires the fewest presuppositions. Besides, stating that our consciousness is material is not particularly restrictive: the only limitations to that statement can be found in the way we consider matter.

Let us assume, then, that human consciousness is a causally emergent property of the brain.

Consciousness as a property of matter

The difficulty faced here is that the fundamental properties of consciousness – perception and action on the material world – cannot be thought of as emergent properties. Indeed, it is not conceivable to find any "composition of different material systems" that would lead to the apparition of "subjective perception of something," nor does it make sense to say that "subjective action on matter" is a "substitute for a more complex description of composites." Subjective perception and action are not substitutes for anything else; they are directly experienced as single.

Visual perception, of course, can be thought of as the combination of a system that transforms photons into electric signals and another system that perceive those signals. We could then separate the latter into a subsystem that builds a visual representation from the input signals by analyzing them and another subsystem that perceives this representation. But the perception "of something" always remains as a whole in either system. The ability to perceive something is a core property that cannot be reduced into a combination of different elements. The same applies to action: choosing to move one's arm can be thought of as an emergent property, but not the act of choosing "something" itself.

Let us make this analogy: a certain type of movement, such as a circular movement, could be an emergent property of a system, but it requires the ability to move as a property of the matter of which the system is composed. Obviously the ability to move itself is too fundamental to be emergent. Perception "of something" and action "on something" are of the same kind.

At this point of the discussion, if we still want to reject holism, we have to conclude that the fundamental properties of consciousness – perception and action irreducibly mixed – are properties of matter itself; or, more poetically, matter is a spiritual substance.

This conception is known as panpsychism. My conclusion here is that with regards to the properties of consciousness, panpsychism is the only naturalistic alternative to holism.

The emergence of the mind

Panspychism may not be the easiest way – holism or dualism would have been much easier – because it has to account for two obvious points that seem to be in contradiction with it:

- Apparently, matter is *not* a spiritual substance. Inert matter does not show any sign of consciousness; it obeys simple causal laws.
- Our mind seems to be a macroscopic inseparable entity, but matter is always separable into smaller particles.

The second contradiction is sometimes denied, in that a stone, a crystal or the oscillation of a string are macroscopic entities although they are composed of smaller particles (e.g. Tegmark, 2000). However, this point is not acceptable since those entities as a whole only exist inside the representation of an observer. They are arbitrary and nothing in them is absolutely irreducible, whereas our mind is always experienced as single, no matter what we do or think about it.

Actually we can solve those contradictions if we assume other hypotheses:

- There exists an aggregation property of matter by which small "spirits" can form bigger inseparable "spirits" by coalescing.
- This process is realized only under specific conditions. It is especially operative inside the nervous systems of living creatures while almost non-existent in non-living matter.

We can assert that inert matter seems to have no mind only because it does not benefit from the aggregation properties; therefore its "minds" are microscopic and have no substantial effect on our scale, as the average action of their fluctuations results in practically deterministic laws. Conversely, living creatures might benefit from this process to allow the emergence of a macroscopic irreducible mind.

Of course, this aggregation process, the conditions of its realization and a possible link between these conditions and the other specificities of our mind, such as communication, reasoning or memory, will have to be identified more precisely.

A shared ontology

These considerations lead us to a conception of the material world where matter is populated with evanescent spirits that may under very precise circumstances aggregate into a bigger mind.

It goes without saying that those micro-spirits cannot be compared to human consciousness. They have no memory, no cognition, no scale and no persistence. They are not "really" conscious. Besides, we know what it is to be unconscious, for example when we fall asleep, and recognize that there is a continuum between conscious and unconscious states. We can

also observe this continuum in natural species: a monkey or a dog seems more conscious than a fly or a worm. The point is: why should we put any boundary to that continuum? Why not assume consciousness is basically a property of any kind of material system, and even of matter itself, that just takes different and more or less intensive and macroscopic forms?

Assuming this continuum of consciousnesses and its absence of boundary, the difference between emergentism and panpsychism lies merely in a more or less broad definition of consciousness. No doubt particles of matter are unconscious in the common sense of consciousness. Panpsychism pleads for a wider definition of consciousness – let's call it "proto-consciousness" to avoid confusion – of which our consciousness would only be a specific and very elaborated and intensive form, involving emergent properties.

I have not dealt yet with high-level aspects of consciousness. My approach so far has been upstream of them: I have tried to explain the preconditions of their existence, i.e. subjectivity itself, and this fundamental point could not have been derived from the understanding of the different functional aspects of our cognition but required a more radical approach, starting from a first-person point of view.

With this approach, I reached the conclusion, which derives from materialism itself, that matter and spirit may share the same ontology but in different forms, scales and intensities. Matter exists in the same way that we exist. This common single mode of existence consists of the association of attention and intention in an irreducible stream of consciousness, tightly related to the flow of time. Our mind is thus the result of an aggregation process over these properties, which occurs inside our brain.

The next step will be to study the compatibility of this conception with our knowledge of the physical world, i.e. to what extent it is possible to find the fundamental properties of consciousness and the associated aggregation process as properties of matter itself.

3. Consciousness and Physics

Determinism cannot account for consciousness

If one accepts my definition of consciousness – perception and action mixed in an inseparable entity and following the flow of time – one can understand easily why the mind-body problem has always been a great difficulty for past philosophers. These properties are indeed totally incompatible with everything we know about matter, at least according to the conception of it we find in classical physics.

This conception of reality cannot account for our mind and subjectivity for three main reasons:

- It is deterministic. Nothing such as a free will can exist. Of course, there is no problem if free will is an illusion.

- It is reductionist. Nothing inseparable at a human scale such as our mind can exist.

- It is reversible. No instant is privileged. There is no way to discriminate between past and future – except statistically through entropy – and no way to define the present and its thickness.

Therefore, according to this view, the arrow of time is a statistical illusion. As indicated above, free will is also an illusion: everything was decided at the origin of the universe. Finally, present and consciousness itself must be illusions, too, because nothing is irreducible and no moment is privileged. But if our mind itself is an illusion, one could ask: for whom exactly is it an illusion?

This conception of materialism is contradictory because it denies consciousness, whereas this model is itself produced by our consciousness. Unless one opts for an epiphenomenal dualism to explain his/her existence, which would leave consciousness practically unexplained, assuming that the representation of the world offered by classical physics describes reality itself in a sufficient way to account for consciousness leads to absurdity.

Quantum physics

Fortunately the description of reality offered by classical physics is not accurate. A very different reality was discovered with quantum physics in the inner foundation of our whole material world: the elementary particles. Quantum physics is today the most accurate description of matter in our possession. It cannot be indifferent to the project of building an ontology, and especially a panpsychist ontology. Let's review briefly the content of the theory.

In quantum physics, any set of particles can be represented as a wave, called the "wave function", which can be described as a superposition of simple states. There are several equivalent ways of describing a single wave as a superposition, each corresponding to an observable characteristic of the particle: its speed, position, energy, and these descriptions are mutually incompatible – which means that a simple state for one description is a superposition of states for another one and vice versa. The quantum theory simply tells us how the wave function evolves with time.

Measuring a particle consists of preparing its environment so that a particular description of its wave function, i.e. a particular observable characteristic, is favored. During the measurement process, the state of the particle is projected from a superposition into a single state for the favored description. This projection is random, with probabilities depending on the weight of the simple state inside the former superposition.

When particles interact with each other, they become entangled – or coherent – which means that they share the same inseparable wave-function, for which each simple state is a combination of characteristics for every particle. Practically, this results in some

correlations between the measured characteristics of different particles or, one might say, several particles "sharing the same randomness." Entanglement is non-local and the correlations can be observed whatever the distance in time and space between entangled particles. Entanglement disappears over interactions with the environment: the possible entanglements are then so numerous that it is virtually impossible for a system to remain itself coherent. This is known as the decoherence phenomenon.

The physical existence of the wave function prior to the measurement is attested to by correlations and interferences between the superposed states, which have statistically measurable effects, whereas the existence of its collapse is attested to by the obviousness that only a single state is ever measured on a particle: the wave function collapse, while not being really part of the theory, is necessary to account for our empirical measurements.

The exact nature of the wave-function collapse is subject to interpretations. Whether this collapse is a physical process, an heuristic one or even an illusion remains unclear. Practically, an external observer can describe a measurement process as the entanglement of an experimenter, an apparatus and the observed system, without any collapse until he/she actually interacts with the system.

The wave function collapse as a unitary act of consciousness

Following this brief summary, we can see that quantum physics offers all the properties needed to account for consciousness:

- Inseparability: reductionism is only a good approximation on a large scale. On a smaller scale and for very short durations, systems are often inseparable because of entanglement.
- Indeterminacy: determinism is only a good approximation on a large scale, due to the law of large numbers. At a microscopic level, matter's behavior is fundamentally random.
- Irreversibility: though physical laws are still reversible in quantum physics, the wave function collapse is an irreversible process.

It appears that the wave function collapse crystallizes all previously discussed fundamental aspects of consciousness.

Indeed, this process mixes perception and action in a single movement: it is involved for an observer in any act of perception of the material world, and it modifies the state of the observed particle in a fundamentally unpredictable way by projecting it on a simple state. Following a particular definition of free will for which the state of an entity cannot be reduced to a function of the information available to that entity, Conway and Kochen (2006) recently demonstrated that elementary particles do have free will.

The wave function collapse is also an irreducible process: it applies to a whole system of entangled particles in a coherent manner and thus cannot be separated into independent processes. Entanglement plays the role of an aggregation process relative to the wave function collapse.

Last but not least, the wave function collapse shares the same relationship with time as consciousness. Nonetheless, it is temporally asymmetrical and can differentiate a past and a future direction, but its exact moment is unknowable from outside the system. Indeed, the only way to know if the phenomenon has occurred is to measure a system, thus provoking the phenomenon itself. The same could be said about the present: if we want to know if an event is present, we have to observe it, and if we do, it is indeed a present event. In that sense, the moment of the wave function collapse can be understood as the subjective "present" of the system it applies to.

As we can see, the wave function collapse features all the characteristics of proto-consciousness: it is irreducible and mixes perception and action on the world according to the flow of time. If not a genuine physical process, the wave function collapse appears to be the *description* of a unitary act of proto-consciousness.

Free will and randomness

If the wave-function collapse is to be assimilated with an act of consciousness, then intention lies in the randomness of the collapse.

It is often objected that randomness cannot be identified with free will, but this is untrue. The confusion comes from the common conception of randomness as something meaningless and blind – in the sense that we say "I don't make decisions randomly" – whereas from a scientific point of view, it should only be considered as something unpredictable and outside our knowledge, which is precisely supposed to be the case for free will from an external point of view.

It is important to make a distinction between two types of randomness, which are two different ways for something to be unknown: the epistemic and the ontological ways. The epistemic way means that something is practically out of the extent of our knowledge because of the situation, but not by principle. The ontological way means that it is fundamentally unknowable. The randomness of quantum physics is of the latter nature. It is an intrinsic ontological randomness. We could call it transcendent, as it lies beyond the possibility of a complete description. Only an ontological randomness might be identified with a genuine free will.

A common objection to this identification is that having some probabilities associated with possible events is in contradiction with a free will. However, any system has an *a posteriori* statistical distribution, even when every single event is unpredictable. In the case of free will, statistical predictions can play the role of propensities affecting the will. This only

implies that our free will is not omnipotent but has some causes that affect it – which we knew already. Another way to say this is to reverse the question: what kind of model of the manifestation of free will from an external point of view could we establish if not a random one?

Randomness and free will are objectively indistinguishable. We usually distinguish between them by assuming that creatures that look like us, such as animals and other humans, do have a free will like ours (Searle, 1992). In other worlds, we talk about free will when something unpredictable is associated with a supposed subjectivity, whereas we talk about randomness when it is supposedly not. Consequently, if the wave function collapse describes an act of consciousness associated with a material perception, its randomness is not "blind" anymore and can be identified with free will.

4. A Quantum Ontology

The instantiation of objective reality

A close look at our physical knowledge leads to the conclusion that the wave function collapse can clearly be identified with stream of consciousness, and that entanglement can be identified with an aggregation process that would possibly allow the emergence of macroscopic minds. The only problem left is to understand how this emergence would occur inside our brain. In this section, however, I will put this problem aside to focus on ontological concerns.

The moment of the wave function collapse is unknowable and understanding its exact nature is today a great challenge in the interpretation of quantum physics, known as the measurement problem. I will not enter the debate here, as it would bring us too far. Let us simply say that just as we believe the present is not only attached to our consciousness but exists in the outside world, we can reasonably assume that the wave function collapse occurs in the physical world, not merely through our conscious perception. Incidentally, we must admit that subjectivity is itself a property of matter.

Let us assume that the wave function collapse occurs somehow through material interactions. This assumption is a clue for understanding how an objective reality and the appearance of an absolute present emerge. Indeed, a collapse can thus be understood as an instantiation of an inter-subjective reality shared by different interacting systems; on a more global scale, the sum of these processes can be thought of as the continuous creation of a common present.

This view is consistent with the theory of special relativity, which states the locality of time and the nonexistence of an absolute present and is best described by the relational interpretation of quantum physics (Rovelli, 1996). According to this interpretation, the wave-function does not describe the absolute state of a system but rather its state relatively

to an observer. The collapse is the consequence of the observer interacting with the system. By implication, the illusion of an absolute present and an objective reality would be a macroscopic approximation emerging from and reinforced by the continuous material interactions, just as determinism and separability are emerging at a macroscopic level – an approximation so close to certainty on our scale that it would be insane not to believe in the existence of an objective reality.

Decoherence is the process by which superposed states become undetectable. The only objective evidence we have for a superposition of state is the presence of interferences between states that have a statistical impact on the result of future measurements. Those interferences disappear with decoherence through interactions of a system with its environment. Decoherence is a measure of the impossibility to go back to a previous state where different alternative realities would still be observable. Taking the relational interpretation seriously, this can be understood as a measure from an external observer of the probabilities that the wave function collapse actually occurred inside a system.

According to this view, the wave-function collapse is a collective process by nature, which arises from interactions. The same could be said about consciousness: being conscious is being immersed in an environment and interacting with it.

The quantum ontology

By comparing the wave function collapse with the stream of consciousness, I am suggesting that a "shared ontology" of mind and matter is compatible with and strongly supported by our knowledge of the physical world. Reasoning from the prerequisites of consciousness in a material world actually led to an exact description of the properties of the wave function collapse. Unsurprisingly, a possible link between consciousness and quantum physics has been considered as a strong hypothesis by many thinkers, including Hameroff and Penrose (1996), Beck and Eccles (1992) and Stapp (2007).

It has been suggested that attempting to establish such a link creates two problems out of one. Obviously, the contrary is closer to the truth: we can make only one problem out of two, the measurement problem and the mind-body problem, by realizing that they are both different aspects of the same question, applied either to matter in general or to human beings in particular, and that question is: what is it to be and, more precisely, what is the relationship between the being and its objective manifestation. It is actually the archetypal question of ontology.

That question cannot be fully answered, but we can enhance the ontology proposed here with the help of quantum physics. This physics teaches us that the state of a system, which is the part of it subject to causal laws, is not a complete description of the behavior of that system but rather a probabilistic description of its possible manifestations. The wave function collapse, a random and unknowable process, must be added to the theory to account for the empirical behavior of matter. We can interpret this incomplete aspect of the

naturalistic description as the fact that existence is not only the causal expression of a passive state, but also an act which holds an acausal component: the act of being. This fact applies to any material system through the quantum properties and incidentally to human beings and their consciousness. This conception comes very close to the philosophy of Whitehead (1920), according to whom the notions of substance, matter and object are merely abstractions, whereas nature is fundamentally made up of events.

The act of being is an act of manifestation to the outer world, an act of perception and the instantiation of a shared reality. It is anchored in the stream of time. What we are cannot be totally known nor induced from our physical state; it is transcendent. Being is continuously bringing something new into the world by selecting the immediate future. That is what the present is about and also the reason our future does not exist yet.

Nonetheless, the wave function collapse exists only because the wave function exists; analogously, being is only possible through a material existence subject to causal laws which determines our propensities and which is the root of our persistence and continuity, i.e. the part of us which is accessible to scientific knowledge. In that sense, existence is a constant dialogue between material determinism and the spiritual act of being.

A physical definition of consciousness

A difficulty arises with this ontology, which is to define what exactly a "system" is and to make that definition objective. Indeed, entanglement among particles is everywhere and is usually not a pure entanglement: particles are generally in a mixed entangled/separable state. In that sense, the world is a big soup of entangled beings who can never really be dissociated from each other but are never fully entangled. If this is so, how can we account for our own identity?

There are two conditions for the emergence of an objective "system" that would develop an identity:

- The system must be rather independent from its environment. We must be able to distinguish between it and the environment if we want to identify it as an entity.
- The system must be inseparable. A composition of systems is arbitrary, it depends on an observer who chooses to put independent systems together and decree that they form a larger system. Being should not depend on any observer.

We can thus expect from a conscious system that it will be strongly entangled and inseparable, while not being strongly entangled with its environment.

This is actually a more elaborated definition of consciousness, which is nonetheless far less restrictive than what we usually understand by consciousness. Remarkably, this definition is the exact counterpart of the former subjective definition of consciousness proposed

above, based on its fundamental properties, because such a system has exactly the same properties: it is indeed an irreducible entity that mixes perception and action on the world. Instead of having a definition in terms of abstract properties, we now have a physical definition of consciousness through the concept of entanglement.

The boundaries of consciousness

We can explain why inert matter is unconscious from that definition. Inert matter is always separable into smaller composites and its constitutive particles might not be sufficiently separable from their environment. Only certain types of coherent systems can really be conscious. The challenge is to understand the processes that allow their existence.

What is remarkable with this definition is that it implies that the frontiers and intensities of consciousness are variable and cannot be precisely defined. Being conscious is not something binary: an entity is more or less conscious and its consciousness is more or less extended. This imprecise aspect is coherent with human consciousness as we experience it and with what Searle calls the background, as well as with the continuum of conscious states that we can observe in the nature, from the worm to the monkey. Theoretically, we could define an "index of consciousness," which would be the ratio between the inner entanglement of a system and its entanglement with its environment.

At this point, the "hard problem of consciousness," so-called by David Chalmers, has turned into a much easier one. Assuming the ontology proposed here, we can explain why we have subjective experiences from the fact that matter is a spiritual substance in itself. Only our macroscopic coherence remains unexplained.

5. A Theory of Mind

Chaotic systems

From the physical definition of consciousness proposed above, the mind-body problem can be reduced to the question of understanding how the brain can develop a persistent quantum entanglement that is sufficiently separable from its environment, despite decoherence, and why this does not occur in other structures.

This question has already been addressed by philosophers and physicians and different solutions have been proposed, for example by Hameroff and Penrose (1996). Those solutions are often judged as not convincing, as either too speculative or questionable: it is a well-known fact that quantum aspects of matter do not exist beyond the level of elementary particles and it may seem impossible to explain our mind, which is a macroscopic system, with quantum physics, which applies only at the microscopic level, on

a million of million time smaller scale. After all, even very small entities such as proteins can be roughly described in a classical manner.

This section will aim at giving some hints on how to go beyond those common objections to the quantum mind hypothesis while not entering too far in speculation.

In fact, the idea that quantum effects are non-existent on a large scale is mainly untrue: our world is definitely a quantum world. There are two main arguments that support the idea of non-existence of quantum effects:

- Microscopic fluctuations have no impact on a large scale because they are too small;
- Entanglement and superposition of states do not exist on our scale because decoherence is too fast.

The first argument applies only to linear dynamics. Chaotic systems, which are characterized by positive and negative feedback loops, are non-linear systems which show an exponential sensitivity to initial conditions, often referenced as the "butterfly effect," which means, loosely speaking, that fluctuations do not cancel each other out as they do in a linear system, but are instead added to each other and amplified over time. However small a fluctuation is, it will finally affect the global state of the system. That is why such systems are unpredictable.

The fluctuations that cause a chaotic system to be unpredictable are certainly not all quantum fluctuations, and include impulses from the environment as well, but in fact, all quantum fluctuations may have an influence on the global system by slightly causing it to drift. This drift is exponential with time: for a macroscopic system, the necessary time to observe the effect of an atomic-scale fluctuation is only twice the necessary time to observe the effect of, say, the movement of a living cell.

We must acknowledge that linear systems are very particular, and most of our world's behavior is ruled by non-linear processes. This includes, of course, living organisms.

Quantum chaos

The effect of quantum fluctuations on a large scale is not very important as long as those fluctuations are mutually independent. Without any coherence, they can be considered as just noise. This observation leads us to our second argument, which states that entanglement is non-existent at the macroscopic level because decoherence is too fast for an entanglement to persist more than a few billionths of second at a normal temperature and for macroscopic systems. This non-existence is supposed to apply to brain processes as well, as Tegmark (2000) has showed. Entanglement is not something that can be easily measured on complex systems, but this assumption is based on strong theoretical

considerations supported by experiments. At first sight, this simple observation ruins any idea of a brain maintaining an entanglement.

However, recent researches tend to tell a different story. It was discovered that a microscopic algae can use quantum coherence for light harvesting at ambient temperature (Collini, ..., 2010). It has also been discovered that an electric superconducting circuit can violate bell's inequality, which means that the electric current is in a superposition of entangled states at a macroscopic level (Ansmann, …, 2009).

These phenomena may be better understood in the light of other recent studies in the field of quantum computers, which show that chaotic systems on an atomic scale, which are called quantum chaos, can generate and maintain a persistent entanglement despite decoherence. Entanglement is therefore considered to be the signature of quantum chaos (Chaudhury, 2009, Kubotani, 2003). We can figure it out intuitively as an effect of positive and negative feedback inside the chaotic system, both responsible for constantly enhancing the entanglement and maintaining it in an indistinguishable state for a macroscopic measurement, hence preventing this superposition from collapsing through decoherence. Another possible explanation is the existence of a Zeno-effect occurring because of the feedback loops involved or, loosely speaking, because the system constantly measures itself. As suggested by Stapp (2007), such an effect could possibly maintain entanglement.

It would seem from these observations that a good candidate for a system able to generate a consciousness would be a chaotic system that operates on an electric field – because electrons are very light and indistinguishable particles subject to non-local behaviors – and whose feedback loops are at a quantum level.

The neuron and the brain

The evolution of our brain, which is responsible for the evolution of our perceptions and behavior, is ruled by a very complex neuron network in which neurons communicate via stimulating and inhibiting electric signals. Each neuron acts like a transistor that sums up its input signals: if they are high enough, the neuron will enter a firing state, propagate a signal, then go back to its resting state. That is apparently what commands everything we feel and do: millions and millions of signals propagating inside our brain each second through a complex network.

The first important observation is that neurons are chaotic systems on a very small scale, which makes their firing partially unpredictable (Aihara, 2008). The cell membrane of a neuron, which is a few dozen of atoms thick, generates an electric potential maintained by ionic streams. The neuron firing consists of the propagation of an inversion of this potential caused by positive feedback when the potential exceeds a threshold value.

The membrane potential of a neuron is a chaotic system of electrons and the feedback involved is on a quantum scale. All of this makes of the neuron a very good candidate for being a quantum chaos system able to generate a constantly entangled electric field.

The second observation is that the brain itself is a very complex and structured chaotic system with many feedback loops. A single neuron firing or not can completely change its whole evolution in a mid-range time interval. In summary, our brain is a hierarchical composition of chaotic systems down to the quantum scale, one being the elementary unit of the other. By recurrence, the brain could itself be understood as a macroscopic quantum chaos system, generating and maintaining an entanglement of its electric field, at least in the more active areas of its network, and this theory would explain our consciousness.

Is this theory compatible with other theories of consciousness suggested by neuroscience? It is coherent with the fact, attested by researches, that consciousness is not located in one specific part of the brain but rather a matter of coherence among different modules. Edelman and Tononi proposed a model where consciousness is identified with a dynamic core of active neurons interacting through many fast and reentrant connections (Edelman & Tononi, 2000). They proposed a measure of conscious integration based on entropy, which makes it possible to determine the extent of this dynamic core. The measure is higher when a set of neurons share more signal together than with other neurons. Remarkably, entropy is also a measure of entanglement, and this rule becomes identical to our former physical definition of consciousness when applied to any quantum system. It is attested that fast and reentrant neural connections features a high sensitivity to initial conditions. Assuming that such connections are also conducive to the transmission of an entanglement between the electric fields of different neurons, the dynamic core suggested by Edelman and Tononi would indeed be a conscious system according to our physical definition of consciousness.

As we can see, the theory of mind I propose does not contradict other neuroscience models of consciousness but is supported by them and complements them with an ontological approach.

Our consciousness as the driver of a chaotic system

The chaotic nature of our brain, refined with the notion of dynamic core, provides a simple explanation of why consciousness arises inside animal's brain and nowhere else: in fact, no other natural system provides such a mechanism for transmitting a potentially entangled electric field between different cells in a chaotic way.

The study published by Tegmark, which claims to prove that the brain should be considered a classical system, shows calculations of decoherence rates for the firing processes of neurons, which imply that a neuron cannot be in a superposed firing/resting state. This result is quite obvious: no one would suspect such a process involving millions of particles to be in a quantum superposition. However, the assumption that the firing/resting state of every neuron is objective and measurable does not actually contradict the possibility that

the electric field of the brain is in an entangled state, as long as this entanglement remains non-observable beyond a certain scale.

Decoherence indeed occurs when the superposed states of a system becomes sufficiently distinct from each other. Consequently, as long as the superposed states of an electric field are indistinguishable – i.e. all compatible with the same macroscopic state, – they will not collapse. Inside the quantum chaos system formed by our brain, such a global entanglement could be constantly regenerated and transmitted among neurons and would still deeply influence its global evolution, particularly by affecting the resting/firing states of indecisive neurons.

Following this conception, we can understand our mind as the constant measurement and inflection of the state of the chaotic system formed by the electric field of our brain and immersed in a sensory environment.

The chaotic nature of the brain is the key to understanding why the evolution of our thoughts are determined by our memories, personalities and environment and hence partly predictable in a short-term range – as Benjamin Libet's experiences (1985) attest – whereas we still feel we can affect them with our volition. Indeed, the deterministic aspects of our mental states play the role of an attractor, in the sense given by the theory of chaos: they imply a reliable short-term predictability, which can be conceived as propensities, but because a fractal attractor is subject to bifurcations on any scale, it is constantly influenced by microscopic fluctuations, in this case the effect of our volition. The delay for these fluctuations in affecting the macroscopic level may be related to our subjective perception of duration, as corroborated by the model of Edelman and Tononi.

We can infer, consistent with neuroscience, that the most deterministic and computational processes of our minds, such as face or word recognition, which are mostly unconscious, are also the ones that are less subject to a sensitivity to fluctuations, and that learning, by reinforcing some neuron connections, also reduces this sensitivity, making processes less subject to an inflection by our volition, and less conscious. This simple consequence undermines the computational conception of consciousness.

From an experimental point of view, consciousness can be conceived as the residual unpredictability in the evolution of our brain, at the level of its global coherence. In that sense, cognitive sciences, by identifying the predictable mechanisms of our brain, are not the sciences of consciousness but rather the sciences of our unconscious. Unsurprisingly, they tend to reduce the domain of our consciousness, but we can be confident that an irreducible residue will always remain.

Conclusion

A theory of mind should focus firstly on our subjectivity, because this is what comes first: any third-person assumption has its foundations in a first-person experience. Paradoxically,

the objective representation of the world built by science is only possible through the exclusion of subjectivity, thus giving rise to the mind-body problem. A solution to this problem will only be found inside an ontology that encompasses the first-person and the third-person perspectives, i.e. the being and its manifestation.

That is what I have tried to construct here. I defined consciousness subjectively as the association of perception and action in a single and irreducible movement. I showed that these fundamental properties cannot be emergent and must be properties of matter itself. I identified them with the quantum properties of matter and this led us to a quantum ontology of mind and matter and to a physical definition of consciousness based on entanglement that can account for our subjectivity and its boundless aspects, for the objective world and for the continuum of states between consciousness and unconsciousness. Finally I gave some hints on how and why consciousness appears specifically inside the nervous systems of living creatures and I showed the accuracy of the description of our mind as the driver of a chaotic system.

It appears that despite frequent criticism of approaches to the mind-body problem that involve quantum physics, the only naturalistic alternative to dualism or holism is to take into consideration the deep changes brought by this physics to our conception of the world. Moreover, it is possible to go beyond the common objections to quantum mind, and as I have suggested, this approach is coherent with neuroscience models of consciousness and supported by scientific observations and philosophical considerations.

These discussions lead to further questions, the first category of which would be how we could eventually support or disprove these hypotheses through experiment. Different approaches may be foreseen, such as seeking a violation of Bell's inequalities in the electric fields of the brain or of a single neuron, formalizing the proposed definition of consciousness and studying its correspondence with neuroscience models of consciousness or studying further the relationships between chaos and entanglement. The second category concerns eventual philosophical and epistemological implications of the interpretation of quantum physics, the measurement problem and its tight relation with time and with the objectification of reality, as well as further considerations of consciousness and the nature of *qualia*, which has only been touched upon in this paper.

Finally we could consider more speculative investigations, derived from panpsychism, of an eventual role of entanglement in human communication, psychology, social mechanisms or in the genesis and organization of life.

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