# The Subjective Interpretation of Quantum Physics

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## Abstract

*This paper proposes a new interpretation of quantum physics that encompasses the first-person and third-person perspective and provides a solution to the mind-body problem. First, a definition of phenomenal existence and a simple metaphysical model of mind are derived from the principles of irreducibility, distinction and persistence. Then it is shown that this process of existence can be associated, within physical representation, with the wave function collapse of quantum physics. A new interpretation of quantum physics, close to the relational interpretation, follows and the relational nature of our scientific knowledge is emphasised. Finally, in light of this interpretation, I analyse the differences between plain existence and consciousness and determine the physical condition for emergence of the latter. This view is confronted with neuroscientific models of consciousness.*

## About the author

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## Introduction

Our scientific knowledge is often implicitly considered as an ontological candidate: it is supposed to describe what reality is so that it may be observed or experienced as such. The mind-body problem arises when one tries to reinsert the subject of this experience into the model of what is experienced. Following a scientific description, any subject, as an object for another subject, is a quantity of interacting particles that apparently nothing unites as an entity nor distinguishes from its environment. While such a description can seemingly account for every manifestation of that subject to the outer world, it does not appear to explain her existence as an entity capable of experiencing. In this way, the mind-body problem could be reformulated as follows: how does the being relate to its empirical manifestation?

Another dilemma – the measurement problem of quantum physics – strongly echoes this one. The measurement of a microscopic system involves a probabilistic operation by which we infer expected observations from the mathematical representation of the system. The problem arises when one tries to reinsert this operation into the physical model. It does not seem to be an objective physical process despite being necessary to account for our experience as a subject. This puts into question the nature of both the scientific model and the associated observation operation. The measurement problem can be reformulated as follows: how does the physical model of reality relate to its empirical manifestation?

The strong analogy between these problems, which are both at the frontier of ontology and epistemology, suggests that they could be solved by broadening our view to encompass both the being and its manifestation – the first-person and the third-person perspective – into the same ontology. Rather than trying to fill the explanatory gap between the experience of being and the models provided by science, incorporating both of them into the same description would require acknowledging their fundamental incompatibilities and putting each in its rightful place. Our ontology should not attempt to be a new physical theory, nor just an update including existence as an additional feature. Instead, it should aim to be a new interpretation of our scientific knowledge which would disentangle its relations with existence. In this essay, I will provide an interpretation of quantum physics that fulfils this goal.

To succeed in this endeavour, I suggest the following approach. To begin with, I will attempt to describe existence and its foundation; I will derive a definition of phenomenal existence from a few fundamental principles and build a simple first-person model of mind. Secondly, I will extend those principles to the world itself and relate them to the scientific description of matter drawn by quantum physics, thus relating the being and its manifestation. From this step a new interpretation of quantum physics will arise. Lastly, I will tackle the mind-body problem more pointedly in light of the previous considerations by providing a model of mind that confronts our scientific knowledge, including the neuroscientific models of consciousness.

## 1. Consciousness and Metaphysics

### *What Is it (Like) to Be?*

To begin with, I propose a metaphysical definition of existence that will serve as a starting point for building an ontology. This definition aims at being phenomenal and fundamental:

- Phenomenal in that it is a first-person definition, which is independent of the assumption that there exists an objective reality and precedes any kind of scientific knowledge.

- Fundamental in that it is not by principle restricted to human consciousness, nor concerned by any specific aspect of human cognition. I am only interested in phenomenal existence in its broadest possible sense. In that sense, consciousness will be construed as a peculiar form of existence, as detailed in section 3.

I will derive this definition from a few generic principles, namely: irreducibility, distinction and persistence.

## *Me and the World*

The first requirement for existence is to be irreducible.

If what I am could be divided into smaller, independent components and then described solely as the set of those components, then we would have an arbitrary definition based on a relative choice. Existence is an ontological terminus; it is experienced as single and comes before any relative consideration of composition and grouping. Therefore existence is irreducible.

The second requirement for existence is to be distinct from 'something else'. In accordance with this requirement, if something exists that is me then something else must exist that is not me, which I will call the *world*. Additionally, it supposes that there exists an interaction between me and the world, otherwise I would be indifferent to its existence and the assumption that it exists would have no sense from my perspective. This consideration is to be related with Husserl’s notion of intentionality which states that consciousness is always consciousness of something; it is always directed at something.

Hence without any interaction, I would not exist. It is thus reasonable and parsimonious to assume that nothing remains beyond that interaction – that there is no soul. 'Me', as an inner state, is empty. Therefore I can be identified with that interaction and only that interaction: I am an interaction with the world, a relation to the world.

This assumption can be related to Sartre’s existentialism. In a sense, it is another way of saying that existence precedes essence. From that perspective, my state, including my mental and corporal state, are not 'me', but belong to the world: they constitute the privileged part of the world I interact with. Though I can still call them 'me', it is in a new sense which expresses the totality of my experience of the world, or 'my world'.

The 'phenomenal identity' thus defined is merely a point of view. It is a first-person 'me' that is distinct from another third-person 'me', closer to the common perception of identity. The latter, let us call it the social identity, emerges when I become an object for others, either by means of my body or my person, and identify myself with this object. It can be considered a construction – a representation – and is subject to illusions, whereas my phenomenal identity is not constructed but experienced and is not subject to illusion but is, by definition, given.

## *Me and the Stream of Time*

The distinction requirement, along with the parsimonious principle, not only entails that I am an interaction with the world, but can also lead to a qualification of that interaction.

Let us specify that being distinct is to be understood in a strong sense, which involves a reciprocity. It means not only that I am not indifferent to the world, but also that the world is not indifferent to me. Being distinct from the world means that what I am cannot be completely deduced from the state of the world I interact with. What I am is not exhausted by something that is not me.

Thus part of me is private, unknown to the world, but without a proper state to mark that distinction, the only distinguishing factor is the interaction I am that brings something new to the world. I am thus a particular kind of interaction: not a static relation, not a causal process, but an unpredictable transformation of the world.

This view is supported by the central role played by intention in our experience of existence, and again, this is to be related with existentialism: for Sartre, existence is absolute freedom. This does not mean that I have no constraint at all, no foundation on which to be free, but that freedom is precisely what existence is.

If I am not indifferent to the world and if the world is not indifferent to me, we can assume that something 'new' flows from the world to me and from me to the world. Thus, I am a process with inputs and outputs. I will call my inputs '*perception*' of the world, which involves, in the case of human beings, all that I am aware of and feel as well as my mental states, memories, ideas, emotions and sensory perceptions. I will refer to my outputs as '*action*' over the world. It includes my spontaneous will, what I choose to think about as well as the decisions and physical actions I make.

Both perception and action are necessary. With no perception, I would be a 'blind' random process. With no action, I would be a spectator of myself – an epiphenomenon – and my existence as a distinct entity would be left unexplained.

We can assume, then, that my interaction with the world is a mixture of both perception and action. However, given the irreducibility of that interaction, both are actually different aspects of the same movement: what is perceived is what is being transformed, and what is acted is the result of the transformation. Both are my mental state, where intention accompanies attention, and conversely.

Interestingly, a directional principle is introduced by those two fundamental aspects of existence. Indeed there are two distinct directions from my perspective as a process: toward my inputs, let us call it the *past*, and toward my outputs, let us call it the *future*. Existence thus introduces a time flow dynamic by generating novelty.

Time is a logical consequence of my differentiation from the world as a process and can be defined by the process that I am. We may consider later that a stream of time exists independently in the outer world. However, from a first-person perspective, the only possible basis for defining the subjective arrow of time is our perceptions and actions.

Distinction saves us from having to introduce an arbitrary separation between me and the world as well as an arbitrary index of present. Indeed, if the process that I am cannot be determined from the state of the world it applies to, then unlike a timeless causal principle, I have a reason for existing in a particular moment that is singular. This particular moment is the 'now' wherein I bring something new to the world. Only novelty can define the present as a privileged moment, from which the future is still undecided, and explain the singularity of every lived moment.

## *Persisting Me*

The third requirement for existence is persistence, although one may consider it more an empirical property of human consciousness than a strict requirement for existence. However, without persistence, existence would vanish as soon as it appeared. I would not consistently exist.

Persistence means that the process of being is somehow related to its continuation. What flows from me to the world is processed again by me, or in other words, something flows from me back to myself. Of course, a process is unique and irreducible and cannot be its own continuation. Persistence thus exists at the level of the similitude between two sequential processes. If the part of the world to which my action applies is processed again, then part of my action becomes part of my perception which is processed into action, and so on. I exist continuously. In this manner, the more overlapping that occurs between the parts of the world that are processed, the more this process becomes continuously 'me'. Such a continuation link could be related to Husserl's notions of retention and protention.

This continuation link cannot be exclusive, otherwise a process would no longer interact with the rest of the world and distinction, thus, would not be fulfilled. This means that my action is somehow disintegrated into several parts of the world with one of them being the input of my continuation. The others can be understood as my effective actions on the outside world. Similarly, the continuation link holds that my perception integrates different parts of the world with one of them being the output of my predecessor. The others can be understood as my effective perceptions of the outside world.

Implicitly, a more restrictive 'phenomenal identity' – in the form of an 'internal state' – is thus defined. My internal state is the dynamic part of the world that is continuously subject to perception and action, whereas the parts of the world subject to just one or the other make up its gradients.

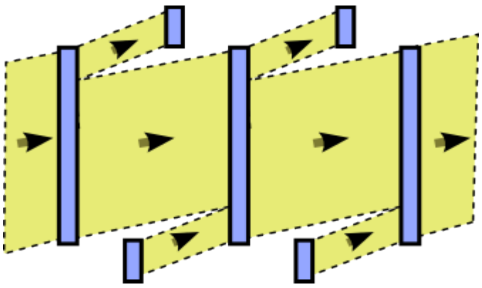

*Figure 1: a persistent process of existence*

Such gradients between what is perceived and what is acted result in a representation of the process of being as a stream from perception to action. In this stream, perception is actually a perception delta that is constantly being integrated into a current state which generates, in turn, an output delta. Whereas with a single process what is perceived and what is acted is the same 'part of the world' and no such thing as a current state exists, for a persistent process a differentiation is introduced between perception and action, and the notion of current state emerges. Persistence allows us to build a model of first-person existence (represented in Figure 1) which comes closer to our intuitive representation of it.

The nature of 'what is processed' – let us call them *qualia* – may seem unclear. *Qualia* are what is given to me as a process. It seems that they cannot be further analysed.

One may observe that the global intensity of an existing state in this model depends on the strength of the perception and action gradients. Too much action results in the disintegration of the internal state of a process into the world, as its continuation shrinks and becomes indistinct from other destinations. Conversely, too much perception results in the absence of a strong identity since the previous state, indistinct from other sources, vanishes. Persistence of existence could be a rather difficult state to achieve in the natural world. This observation will be addressed in detail in section 3.

## *A Starting Point*

From three implicit requirements – being irreducible, differentiable and persistent – we arrived at a minimal definition of existence: an irreducible process which continuously mixes perception of and action over the world in a stream of time. We also developed a model of persistent existence.

In our model, identity arises from feedback loops between our perceptions and actions. An internal state is defined as outputs that will be perceived 'after'. If we accept a looser definition of 'after', we can imagine that there exist more than one loop, of different duration, for any given persistent entity. As a result, my persistent phenomenal identity – or, my internal state – would have different degrees of intensity among different parts of the world and no clear frontiers: the shortest loops would mark its centre and the longest loops its periphery. Interestingly, this point is corroborated by cognitive research showing that the appropriation of one's gesture is based on a comparison of the representations of perceptions and actions inside the brain through feedback loops (Jeannerot, 2002). Moreover, perceptions and actions are always more differentiated when applied to parts of the world that are further from the central area of our identity – motor actions and sensory perception are very distinct features of human beings – and become entangled when applied to our ideas and emotions, or what we call our inner state. Who can say to what extent we perceive our thoughts and to what extent we act on them?

We have a complete and accurate definition of the essence of existence which is not limited to human consciousness, rather it is independent of any human specificity. It corresponds to what we could call 'existing' in its more generic and fundamental phenomenal aspects and, as we saw, phenomenal existence is the starting point for defining everything else, from the material world to the stream of time itself.

## 2. Consciousness and Physics

### *What Is it Like to Be Something Else?*

After having designated existence comes the task, in a realist approach, of defining the world itself, not as what relates to us, but as something existing independently from us. I will now plead for monism by stating that there exists only one type of irreducible process in the world, and that any observed process is either an irreducible process or a combination thereof. One may notice that this hypothesis shares some similarities with Whitehead's process philosophy (1920) and Russell's neutral monism (1921), and with their contemporary followers' approaches as well.

The distinction requirement, defined as non-indifference from and to the world, cannot be thought of as an emergent property, which would be present in a composition while not being present in any of its elements. Trivially, a composition of processes, none of which impact the world, will not impact the world either, and reciprocally. Therefore, distinction has to be a feature of the fundamental constitutive processes of the world. Any irreducible process is a process of being. A detailed argument for this view, which can be considered a panexperientialist view, and its relation with consciousness will be presented in section 3.

Following this monist ontology, a correlate of the process of existence is to be found inside the physical world, and more precisely in the constitutive components of matter, that is, in what is described by quantum physics. We expect that these processes are irreducible, acausal, not indifferent to their inputs and involved in our interaction with the world. In this section, I will show that this expectation is fulfilled within quantum physics. This will induce a new interpretation of quantum physics, which gives a natural place to subjectivity and throws light on the relations between the being and its manifestation. Finally, I will expose some epistemological concerns that emerge as a result of this interpretation.

## *Quantum physics*

Let us start by describing briefly the main features of this physics. Quantum physics has two aspects: a description of physical systems and their evolution in terms of a wave-function, and a description of the measurement procedure – that I will refer to as the 'wave-function collapse' – from which the initial state and final state of a system, in any experiment, are determined and/or predicted.

The wave function is the mathematical description of the correlations between every possible value for every property or combination of properties ('observable') of a system. It evolves with time in a deterministic and reversible way. It is either separable or entangled, depending on the existence of correlations among the properties of different sub-systems. When two systems interact, they become entangled. To each observable corresponds a way of describing the wave function as a superposition of weighted states, to which correspond definite values for that observable, and each state for one observable may be a superposition of state for another one. That is where the correlations lie. Each state is phased and thus may interfere with other states of its superposition. When a system interacts with its environment, an observable is privileged: phases shift contingently and the states of the superposition for that observable no longer interfere. This phenomenon is called decoherence.

When we measure a system, we only ever observe one state for the privileged observable – our apparatus generally plays the role of an environment, – as if the wave function had collapsed from a superposition to a single state. The probability of measuring a certain state is proportional to its weight in the superposition, which includes the effect of interferences. The latter convey the fact that the measured state is still represented as a superposition of states for other observables that could have been measured as well but were not, and that each of those states influences the probability of the current outcome. Through entanglement, the collapse is non-local, atemporal and irreducible. Loosely speaking, entangled sub-systems 'share the same randomness' in different space-time locations and the collapse applies unitarily to those sub-systems, 'actualising' this randomness coherently and accordingly to what is measured for every measurement.

As we can see, both aspects are required. The existence of superposition of states is attested by the statistical effect of interferences, whereas the collapse is attested by the obvious fact that we never observe a superposition, but a single state, for the measured observable. However, since interferences tend to vanish with decoherence for the measured observable, alternative states for that observable tend to have no measurable effects. It follows that the collapse is not observable, and is not a necessary feature in the description of the evolution of a physical system, though it is necessary to account for our final experience, and even for the sole possibility to describe the initial state of any system in an experiment.

The challenge in the interpretation of quantum physics lies in the fact that the theory does not appear to be purely ontological – since the wave-function is a probabilistic description of what is measured – yet still cannot be interpreted in a fully epistemological way since different possible states 'really' interfere together.

## *The Collapse as a Process of Existence*

Let us first consider scientific realism seriously and see how far we can go. We will assume that the wave-function is the exact description of what exists. Since the collapse is not required in this description, we can suggest that it is actually an illusion due to the fact that we are immersed in reality: we are observers entangled with a particular world, whereas superposed states still exist in other worlds. In this interpretation, known as the Many-Worlds Interpretation, the universe is the combination of all possibilities continuously branching out in a completely deterministic and reversible evolution. My consciousness is following a particular path in this evolution, depending on everything that apparently happens around me, whereas other 'me' follow other branches of reality wherein different things happen.

In the Many-Worlds Interpretation, alternative worlds 'exist' despite being unobservable because they are present in our representation of the world and supposedly contain observers. However, following this conception of existence, our past, all our possible futures, as well as any alternative pasts and futures, though not directly observable, 'exist' as well: they are present in our representation and contain observers. It appears that the concept of existence entailed by this interpretation is deteriorated to the point of becoming non-operational in accounting for our subjective experience: it does not tell me why I exist now and not before nor in an alternative reality, why there is a flow of time, why I follow this path and not another one and why with those probabilities. It seems to lack an instantiation, a notion of present, leaving first-person existence unexplained. Since special relativity forbids us from defining an absolute present that would restrict existence to a particular time frame, the only way out is to assign an arbitrary index to each conscious being. However such a theory only transfers the existential question to this mysterious index.

A world with no collapse is a world where existence is either undefined or defined arbitrarily. Conversely, introducing a collapse for a given system – and thus restricting its representation to what is observable – amounts to instantiating a present for that system. Moreover, just like the wave-function collapse, the determination of present is 'tautological': If I am observing an event, then it is *de facto* a present event, and if I am observing a system then it has *de facto* collapsed, otherwise I have no way to know. Just like the present, the collapse would not be part of the scientific model since it is subjective, relative to an observer immersed in reality and thus unobservable except through our own existence. We can interpret the collapse as the physical manifestation of an act of existence through the instantiation of a present.

This interpretation is supported by the fact that the irreducibility and distinction requirements for existence that we defined in section 1 actually apply to the wave-function collapse:

- The collapse is irreducible through entanglement.
- The collapse is unpredictable. It supposes that an acausal process has occurred inside the observed system. In other words, the world is not 'indifferent' to a collapse.
- A collapse is not 'indifferent' to the world either, since it is a projection statistically based on the immediate previous state of the world.

It follows that the collapse is the exact counterpart, inside physical representation, of a process of existence, as defined in section 1. This process is irreversible and differentiates two directions, the past being the superposed state and the future the projected state.

We cannot prove that something perceived the world at the time of a system collapse, since it would require us to be that something, but we can assume that its non-indifference is a correlate of subjective awareness. Moreover, the collapse coincides, for us, with an observation of the world. Similarly, we can assume that the non-indifference from the world is a correlate of subjective intention.

Conway and Kochen (2006) proposed a similar definition of 'free will' and demonstrated that, following that definition, as long as experimenters have free will in the choice of what they will measure, elementary particles do have free will. It has been objected that equating free will to randomness is irrelevant, yet ontological intrinsic randomness is simply the name we give to what we consider to be unpredictable in a system whereas free will is what is unpredictable for us in supposedly conscious systems (Ruyant, 2010), that is to say associated with perception of the world, which is supposedly the case here. The absence of causality implied by this conception of free will may seem absurd, but after all, existence, whose anguish has been emphasised by existentialists, *is* absurd.

## *The Subjective Interpretation of Quantum Physics*

The interpretation of the collapse as the physical counterpart of the process of existence suggests a new interpretation of quantum physics, inspired by the relational interpretation of Carlo Rovelli (1996). In that interpretation, wave function is construed as a description of the relations between an observer and her object. Just as special relativity requires giving up the notion of absolute present, Rovelli's approach requires only giving up the assumption that there exists an accessible objective reality independent of any observer. Only this assumption leads to the problematic Many-World interpretation and other counter-intuitive aspects of quantum physics.

In my interpretation, which I will call the subjective interpretation, the wave-function is a representation of a physical system that may or may not have been 'processed', and as in Rovelli’s interpretation, this representation is relative to an observer. The difference is that, in the subjective interpretation, the observer is not a material system but is itself a process. As observed in Song (2008), this conception of existence as acting rather than having a state has the advantage of solving the problem of impossibility of self measurement. It follows, however, that observable quantities remain in an indefinite state for any observer as long as they are not 'processed'.

In the subjective interpretation, the superposition of state is thus either the representation of the intrinsic indecision of an unprocessed state, or the representation of a system that was processed in an unknown way. Both share the same representation because a 'process' is private and subjective: one cannot know with certitude if it has occurred unless he/she *is* that process.

Consequently, several philosophical options consistent with empirical data can exist within the subjective interpretation. A 'solipsist option' consist in assuming that existing processes only occur when I become aware of something. An 'idealist option' consist in assuming that they occur with human consciousness. A 'materialist option' consist in assuming that they never occur. I will personally assume that existing processes occur in the physical world – thus opting for panexperientialism.

The latter option is grounded in intuition. Intuitively, we all believe that other people are as conscious as we are and that our present is shared with the outside world, while strictly speaking, this is only faith. However, bearing that act of faith, we shall statistically discriminate between a processed and an unprocessed state through the presence of interferences.

Interferences, indeed, reflect the statistical effect of superposed states on the outcome of a measure. This can be interpreted as the probability that alternative states still exist simultaneously, that is, the probability that a system has not yet been processed. Conversely, decoherence expresses the fact that the bigger the system and the more information there is that has leaked into the environment, the less an indecision at the scale of this system can remain for one specific observable and the higher the probability that the system has been processed. The process of existence occurs probabilistically with decoherence, when a system is measured by its environment, and is relational by nature.

If we accept this interpretation of decoherence, we also accept that the many-worlds do not exist. In fact, they vanish with decoherence, but we will not know this until we interact with the world to acknowledge its state. The interaction provokes a heuristic collapse, that is, an awareness of what has been processed in the represented system and an eventual participation in that processing, at the level of what has not been decohered yet. Just as in Rovelli's interpretation, a third person, unaware of the result, would still represent my body as a superposition of state entangled with the observed system until he/she also acknowledges my state or the one of the system. The Many-Worlds Interpretation is just the view of a fictive observer who never processes anything, and thus never 'exists', except when his representation is instantiated.

## *The Nature of Objectivity*

This interpretation has implications on the very status of the scientific representation.

The first remark is that the wave function mixes an epistemological representation and an ontological representation indistinctly. This should not be a surprise: it expresses the fact that we do not have access to reality in itself, rather only to reality mediated by our experience. Consequently we have no means of distinguishing between the incertitude of our own knowledge and the incertitude of reality in itself.

Following the subjective interpretation, reality in itself is nothing but the reality of other processes. As a consequence, no objective reality actually exists: existence is meaningless outside a first-person perspective. Instead, an inter-subjective reality is constantly generated, updated, propagated and reinforced through interactions and requires being a participant to be acknowledged. Reality becomes seemingly objective through its actualisation by material interactions. It is actually just as objective as our measurement of the world can be precise. In other words, objectivity is an emergent property of the world. Incidentally, since existing is actualising a present, the emergence of an approximate absolute present follows exactly the same mechanism. As for Rovelli's relational interpretation, this view is consistent with the locality of time entailed by special relativity.

This leads us to a second remark concerning the relational nature of the scientific representation. According to the subjective interpretation, each wave function is merely the representation of a specific observer. It is the description of correlations between different measurements for that observer. Fundamental properties of matter are not objective. They are not subject to regularities, nor do they follow the laws of nature: only their relations do. The scientific representation of reality is an empty nutshell, or, in Mermin's words (1998), a set of correlations without *correlata*, which entirely rests on a subjective substrate.

In particular, as Whitehead (1920) held, whose position is now defended by the proponents of epistemic structural realism, the scientific space-time can be understood in a fully relational fashion. 'Time evolution' of the wave function is not a genuine evolution but expresses the correlation between time as a measured property and other physical properties. Only the wave function collapse is the manifestation of a genuine evolution of state – the instantiation of a present and an increment of experienced time – but this evolution can only be acknowledge from a first person perspective, trough existence.

There is no sense in asking where or when a collapse occurs since the answer is always 'here and now' – only relations make sense. As already stressed by Rovelli, if we adopt this view several paradoxes of quantum physics and special relativity, such as non-locality in an EPR or delayed-choice experiment, simply vanish. This view can reconcile quantum physics, locality and completeness.

The relational aspect of physical representation should not be a surprise if we acknowledge that language itself is relational by nature. A concept only exists in terms of similarities between different perceptions and, as noted by Quine (1969), there is no definitive understanding of a proposition or concept. Red might refer to my experience with red when I employ it or to yours when you hear it, but 'red' as a universal term refers only to the strong correlation that exists between your experience of red, mine and that of everyone else. In effect, it exists because the word was employed within situations and about objects in which this correlation was solidified. Describing correlations is the horizon of language, and the formalized language of mathematics, on which any scientific description is based, is no exception to the rule. Going any further requires being, living and experiencing, which all are unspeakable: how could we describe our colours and sounds beyond giving them a conventional name?

It follows that the idea of an independent and objective reality, which requires a language to exist, can only be relational and blind to singularity. In acknowledging that, we understand that the 'explanatory gap' between conscious experience and scientific description is merely a misunderstanding of the nature of the latter. A physical theory can only describe how things relates, not what they are. What they are and how they are experienced will always remain subjective and unspeakable.

## 3. Consciousness and Biology

### *Existence and Consciousness*

The monist ontology developed in previous sections reduces the difficulty of the so-called 'hard problem of consciousness' because it is determined that subjectivity is 'all there is', instead of being specific to certain systems or arising from the interactions of a non-subjective material. However, two points still remain to be explained within this ontology:

- the central nervous system of living creatures apparently allows the emergence of an irreducible process of existence at a macroscopic level
- consciousness generally refers to those systems, whereas microscopic processes of existence are supposedly not conscious

Both those observations are related: the latter stresses the necessity to differentiate between consciousness and existence alone while the former inquires as to its emergence at a macroscopic level in particular physical systems. These questions have been put aside until now. The purpose of this section is to fill this gap. I will start by discussing the specificity of consciousness. Then, I will propose a physical definition of consciousness within the ontology developed in previous sections and attempt to find the physical conditions for its emergence. Finally, I will relate these considerations to neuroscience research so as to sketch a clear picture of the physical nature of our minds.

## *The Specificity of Consciousness*

As already observed, distinction cannot be thought of as emergent. The counterpart from a phenomenal perspective is that subjective perception and action cannot be thought of as emerging from a composition either, even though they may be perception of a composition or action over a composition of elements. Just like certain types of movement may be emergent, but not the ability to move itself, sensory perception and motor action, for example, may be emergent, but not subjective perception or subjective action *per se.* They have to be found in the fundamental constitutive elements of the world (Ruyant, 2010 ; a similar argument can be found in Strawson, 1997).

This observation entails that any acausal transformation of the world, hence any microscopic material system, is able to perceive and act subjectively. If consciousness were to be synonymous with subjective awareness, then it would follow that any microscopic process of existence would be conscious. This position, known as panpsychism, seems dubious. Indeed, inert matter does not display the characteristics generally associated with conscious beings, e.g. the ability to adapt to a situation. We cannot prove that something is unconscious, unless we *are* that something – and then it is *de facto* conscious – but we all know that unconscious states exist: when we fall asleep, do not we loose the ability to perceive something subjectively?

By experience, we associate conscious states with beings who display commonly assumed characteristics of consciousness, such as adaptability, because we *know* that when we are ourselves conscious, we display those characteristics (Searle, 1992). However, the decisive question in this matter might be: how do we *know* when we are conscious? Having that knowledge is certainly a sufficient condition for consciousness – what else should we require? – and if we credit our common experience with accuracy in its distinction between conscious and unconscious states, then it is also a necessary one. Considering that the presence of this knowledge along with awareness and intention does not go without saying could shift the specificity of consciousness away from subjective awareness and intention alone, hence weakening the criticism towards panpsychism.

Let us examine the hypothesis that the mere difference between consciousness and plain existence lies in the presence of a knowledge that one exists. This differentiation is wilfully loose: beyond the generic features of existence, different conceptions of consciousness, implying different criteria for being conscious, might be considered, depending on the sense one gives to 'knowing'. However this is not an issue: it only implies that the concept of consciousness is just as imprecise as the concept of knowledge can be. In a restrictive sense, knowing something would imply the ability to report it, and this would require superior cognitive abilities, such as memory and language. With a less restrictive definition, which would be synonymous with 'realizing', solely the ability to build a representation of self and a precise representation of reality would remain an important factor. (This distinction is similar to that between access and phenomenal consciousness).

Arguably, and as actually argued by proponents of higher order theories of consciousness, we are not conscious in every moment of our active life – for example when absent-minded, but still being able to drive home (Armstrong, 1968), or under high concentration – but a reconstitution of our life experience based on short-term memory is regularly performed by our brain to make us believe in a continuous conscious state. The existence of this kind of confabulation is attested by neuroscience researches. Genuine unconscious states, such as sleep, while still featuring some awareness and intention at some level, may simply lack the short-term memory and the active representations of self and reality that are necessary to maintain a coherent 'knowledge of being conscious'.

Following that view, there is no difference in nature between conscious and unconscious existence: there is only a difference of degree and a continuum between them. Consciousness is a peculiar form of existence, which holds the ability to maintain a precise and accurate representation of self and of reality. This continuum would explain the apparent continuum of conscious beings we find in nature.

### *A Physical Definition of Consciousness*

I will now propose a physical model, which, according to the ontology developed in this paper, holds the minimal characteristics of consciousness, defined as the ability for a process of existence to maintain an accurate representation of self and reality. The following minimal conditions can be identified:

- Holding a representation of self supposes that a persistent self exists
- It also supposes that a self-perception is continuously performed
- Holding a representation of reality supposes a continuous integration of perceptions
- The accuracy and precision of such representations supposes a complex and flexible structure

These minimal conditions are fulfilled by the model of a persistent process described in section 1 with the exception of complexity. As a first approximation, we can thus identify consciousness with a persistent process of existence.

In this model, integration and disintegration of inputs and outputs are associated with persistence of an inner state along with a constant interaction with the world. They might also explain why our mind is macroscopic while matter seems separable down to the microscopic scale. Indeed, as illustrated in figure 2, if a spatial asymmetry causes several sub-processes to be integrated into larger ones in series, creating one large input for a process whose output is then disintegrated in series, then we have a 'large' persistent process that may become macroscopic.

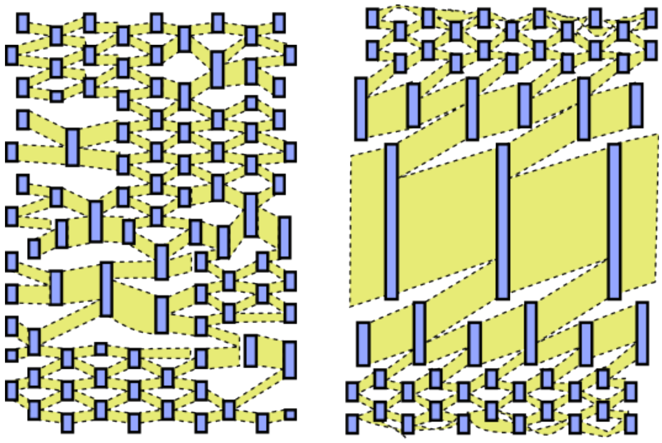

*Figure 2: Inert matter versus conscious matter*

If the process of existence is to be identified with the wave-function collapse of quantum physics, we can identify its integration and disintegration aspects with entanglement and decoherence, respectively. Indeed, entanglement is an integration phenomenon by which a single collapse will apply to different systems. In quantum physics, a measurement is the entanglement of a system with an observer. Similarly, in our model, perception is the integration of an input into an inner state. Moreover, the relation between entanglement and decoherence, wherein the latter is caused by entanglement with different parts of the environment, is comparable to the relation between integration and disintegration. Following this identification, my action over the world, and the reason why, as Sartre said, I am 'condemned to be free', is a consequence of the fact that I am constantly measured by the world.

It follows from that identification that the inner state of a persistent process is a physical system that remains self-entangled and distinct from its environment, that is to say, not as entangled with its environment as it is with itself. The latter condition corresponds to the observation of section 1 that if input and output gradients are too important, the inner state of a persistent process is no longer identifiable and is instead either absorbed by the environment or disintegrated.

Then, as a first approximation, we can assume the following definition:

- A conscious entity is a system persistently more entangled with itself than with its environment

One could notice the similarities of this definition with that of neural assemblies (Noë & Thompson, 2004).

An 'index of consciousness' could be defined, which would be the ratio between self entanglement and entanglement with the environment. Incidentally, this definition implies that the frontiers and the intensities of consciousness are variable and cannot be precisely defined, which is coherent with the notion of 'background' developed by Searle (1992).

### *Chaotic Systems*

The possibility for a physical system to maintain an entanglement despite decoherence at a macroscopic level is certainly a very controversial point. Indeed, quantum mind hypotheses have been suggested by many thinkers (Hameroff and Penrose, 1996, Beck and Eccles, 1992, Stapp, 2007), and faced numerous objections, most of which are based on the consideration that decoherence is a phenomenon through which any entanglement vanishes too rapidly to be observed at the medium scale in a warm environment. However, as I already stressed elsewhere (Ruyant, 2010), this statement is merely theoretical and recent experimental research, for example in biology, tends to tell a different story (Collini, ..., 2010, Ansmann, …, 2009). More importantly, we are not seeking a system that maintains its entanglement and never decoheres but rather a system that would constantly generate an entanglement of its own constitute at a higher rate than decoherence. This option, as Pereira (2003) noticed, is not vulnerable to objections based on a calculation of decoherence rates (e.g. Tegmark, 2000) when no 'entanglement rate' calculation is opposed.

Several characteristics of our model, such as spatial asymmetry and presence of a feedback loop, point to chaotic dynamic. Moreover, entangled states have lower entropy than separable states and the ability to locally maintain a low entropy is a distinctive characteristic of chaotic dissipative systems (Prigogine, 1997).

A possible link between low entropy and quantum entanglement generation has been defended by Pereira (2003). However, a low entropy might not be a sufficient condition. Low entropy reflects the presence of correlations inside a system, but they might be 'classical' correlations instead of a quantum entanglement. Such correlations, as the result of interactions, can be interpreted as the trace of a past entanglement after decoherence occurred, but they do not express the presence of an actual entanglement. In other words, having a chaotic dynamic appears to be a necessary condition for a system to be conscious, but an insufficient one. Another condition is that correlations are generated at a higher rate than decoherence.

Intuitively, we can picture a chaotic system as one which features dilating and contracting dimensions in the phase space, that is, the spatial representation of the possible global states for a system, wherein each coordinate corresponds to a specific global property (Prigogine, 1997). The instantaneous state of a system is a wave packet in the phase space which follows a trajectory, and which decoherence tends to maintain below a constant and small volume, while quantum uncertainty ensures a minimal volume. Along the dilating dimensions, close trajectories diverge exponentially and the wave packet is thus enlarged with time. Entanglement is propagated and, as superposed states become more distinguishable, they are exposed to decoherence. Along the contracting dimensions, distinct trajectories converge and the wave packet diminishes with time. That may prevent a superposition from collapsing, as superposed states become indistinct. The combination of both phenomenons into a cycle, wherein differences for one dimension are 'converted' into differences for another dimension, is at the origin of a macroscopic unpredictability of the system, commonly referred to as the 'butterfly effect'. Basically, any fluctuation may influence the global state of a chaotic 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 two or three time the necessary time to observe the effect of, say, the movement of a living cell or of a grain of sand.

In this intuitive representation, we can speculate that if a typical cycle is faster than the decoherence rate then the system would constantly maintain a self-entanglement and prevent it from collapsing. Such a phenomenon would be comparable to a Zeno Effect.

In this case, the global unpredictability of the system would be completely assignable to the effect of a single persistent process: we would have a conscious system. Furthermore, contrary to models refuted in Tegmark (2000), it is not necessary that the superposed states differ by a macroscopic range in order to have a macroscopic effect with time. In our model, a requirement for the presence of consciousness inside a system would be that the typical rate of the chaotic system, the Lyapunov exponent, is higher than the decoherence rate of that system. Their ratio provides us a potentially more accurate 'index of consciousness'.

This is merely a grounded intuition. Establishing a more rigorous link between chaotic systems and our physical definition of consciousness is beyond the scope of this paper. However, this intuition is confirmed by various results in the quantum-computing field, which show that entanglement generation is a signature of quantum chaos (e.g. Chaudhury, 2009, Kubotani, 2003, Bandyopadhyay & Lakshminarayan, 2005).

## *The Neuron and the Brain*

The cell membrane of a neuron is a dissipative system that generates an electric potential whose dynamic is chaotic on a very small scale (Aihara, 2008), and which is responsible for neural signal transmission. Its constitutes, electrons, are light-weight particles on which decoherence is less effective. That makes of a neuron a typical system able to maintain a persistent entanglement of its electric field. Neurons are themselves involved in a complex network with many feedback loops where chaos plays an important role (Skarda & Freeman, 1990). This combination of chaotic dynamic down to the microscopic scale could bring entanglement up to the macroscopic world.

Edelman and Tononi proposed a neuroscientifical model of the mind strongly supported by experimental research, wherein consciousness is identified with a dynamic core composed by a small group of active neurons interacting through many fast and re-entrant connections (Edelman & Tononi, 2000). This core is connected to various distant parts of the brain. One of its distinctive characteristics is that neurons inside the core have more connections together than with neurons outside the core. It performs a high integration of its inputs: an input on one neuron impacts the whole core rapidly. Edelman and Tononi proposed a measure of conscious integration based on entropy, which makes it possible to determine the extent of this dynamic core. Assuming that entropy is a measure of entanglement alone, that is, neglecting the distinction between classical and quantum correlations, the measure proposed by Edelman and Tononi is equivalent to the first 'index of consciousness' suggested below, as the ratio between inner entanglement and inter-entanglement. As we can see, the simple model of mind proposed in this paper fits perfectly the model of Edelman and Tononi and complements it with an ontological approach.

Following this interpretation, we can understand our mind as the constant measurement and inflection by a process of existing of the state of the chaotic system formed by the electric field of a dynamic core of neurons, immersed in the sensory/representational environment provided by the rest of the brain. It is not necessary that any neuron be in a superposition of firing/resting state, as long as the whole electric field of the dynamic core is in a superposition of indistinguishable states, whose tiny difference could influence indecisive neuron firing in a short-term interval and the whole brain state in a mid-term interval. The delay for such a tiny difference in affecting the global state of the whole system might be related to our subjective perception of duration, as corroborated by the model of Edelman and Tononi.

In this hypothesis, the chaotic nature of our mind is the key to understanding why the evolution of our thoughts are determined by our memories, personalities, desires and environment and hence partly predictable – as Benjamin Libet's experiments (1985) attest – whereas we still feel we can affect them with our free will. 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 since 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. Consciousness can thus be conceived as the residual unpredictability in the evolution of our brain, at the level of its global coherence, and habits, by reinforcing certain neuron connections, would reduce this sensitivity to fluctuation, making processes less conscious.

A macroscopic process of existence, if hardly detectable on a small scale, would remain coherent and thus become prevalent on a large scale while microscopic processes tend to cancel each other out through linear interactions, giving rise to deterministic mechanisms. This observation solves the central paradox regarding consciousness: its apparent reducibility to a huge amount of deterministic mechanisms along with an obvious coherence and unity on a large level.

## Conclusion

It has been said that trying to establish a link between quantum physics and consciousness is making up two problems out of one. In this paper, I tried to show that the contrary is closer to the truth. The measurement problem and the mind-body problem are actually both different aspects of the same question, applied either to matter in general or to human beings in particular, which is the question of the relations between the being and its objective manifestation. By identifying the wave function collapse to an act of existence, we demonstrated that a common ontology can account consistently for both mind and matter in coherence with our scientific knowledge of the world. This ontology, which describes being as a transcendent act, aim at creating a link between science and phenomenology.

Addressing this question did not solely imply developing a theory of mind within our scientific knowledge but also reconsidering the status of science itself. Scientific theories should not be understood as a description of nature, but rather as the description of the framework where the unspeakable takes place, or a relational objectivity entirely subordinated to subjectivity. Following this view, reality is a dialogue between structure and transcendence, which chaotic dynamic brings to the macroscopic world, giving birth to our minds.

These discussions lead to further questions, the first category of which involves how we could eventually support or disprove this conception through experiment. Different approaches may be foreseen, such as seeking a violation of Bell's inequalities in the electric fields of the brain, or studying more rigorously the relationships between chaos and entanglement. The second category concerns philosophical investigations such as an eventual formalisation of the subjective interpretation of quantum physics, the process theory that accompanies it and further considerations of consciousness and cognition in its more elaborated aspects, which has only been touched upon in this paper. Finally, we may consider more speculative investigations derived from panexperientialism of an eventual role of entanglement in human communication, psychology, social mechanisms or in the genesis and organisation of life.

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