Can the Many-Worlds-Interpretation be probed in Psychology?

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Abstract

A minimal approach to the measurement problem and the quantum-to-classical transition assumes a universally valid quantum formalism, i.e. unitary time evolution governed by a Schrödinger-type equation. As had been pointed out long ago, in this view the measurement process can be described by decoherence which results in a "Many-Worlds" or "Many-Minds" scenario according to Everett and Zeh. A silent assumption for decoherence to proceed is however, that there exists incomplete information about the environment our object system gets entangled with in the measurement process. This paper addresses the question where this information is traced out and - by adopting recent approaches to model consciousness in neuroscience - argues that a rigorous interpretation results in a modern perspective on the von-Neumann-Wigner interpretation – namely that the information that is or is not available in the consciousness of the observer is crucial for the definition of the environment. As such the quantum-to-classical transition while being difficult or impossible to probe in physics may become testable in psychology.

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The problem of how to understand the quantum-to-classical transition dates back to the early years of quantum mechanics. Among the various interpretations of the quantum measurement process the ”Many Worlds" or "Many Minds" interpretations (MWI) [1, 2] are recently becoming increasingly popular [3]. This scenario is attractive as it does not introduce any new elements into the formalism of quantum mechanics which go beyond the unitary evolution governed by a Schrödinger-type equation, and can in this sense be understood as ”minimal” or ”conservative”.

In the following we briefly review the measurement process and the role of decoherence in the MWI, before we concentrate on the crucial importance of the observer's perspective.

In quantum mechanics, the state vector $|\Psi\rangle$ describes the complete knowledge about a system and evolves deterministically according to a Schrödinger-type equation

$$i\frac{d}{dt}|\Psi(t)\rangle = H|\Psi(t)\rangle. \tag{1}$$

The state vector does not, however, unambiguously determine the outcomes of measurements. What happens during a measurement can be easily illustrated by adopting a spin-1/2 or Q-bit object system $|\Psi\rangle \sim \{|\uparrow\rangle, |\downarrow\rangle\}$ which is coupled to a measurement apparatus with states $\{|0\rangle, |+\rangle, |-\rangle\}$. In the measurement process the object system gets entangled with the apparatus and unitary evolution yields a state vector $|\Psi_{\rm tot}\rangle$ for the complete (object + apparatus) system

$$\begin{aligned} |\Psi_{\rm tot}\rangle &\sim |\uparrow 0\rangle \rightarrow |\uparrow +\rangle \\ |\Psi_{\rm tot}\rangle &\sim |\downarrow 0\rangle \rightarrow |\downarrow -\rangle. \end{aligned} \tag{2}$$

In general our object system will be in a superposition $|\Psi\rangle \sim \alpha_\uparrow|\uparrow\rangle + \alpha_\downarrow|\downarrow\rangle$ which in the measurement process then evolves via

$$|\Psi\rangle \sim \alpha_\uparrow|\uparrow, 0\rangle + \alpha_\downarrow|\downarrow, 0\rangle \rightarrow |\Psi\rangle \sim \alpha_\uparrow|\uparrow, +\rangle + \alpha_\downarrow|\downarrow, -\rangle. \tag{3}$$

The latter two terms then correspond to the infamous Everett branches, ”Many Worlds” or ”Many Minds”: if the apparatus is understood as observer the experimentalist will find herself within one of the branches and will not experience any alternative realities. The understanding of the measurement process as a coupling of object system, measurement apparatus and observer is known as the von-Neumann chain [4], and it leads immediately to a new problem: where in this chain is the quantum-to-classical transition, also known as ”Heisenberg cut”, happening? In principle there could always be an outside observer ("Wigner's friend") who would experience her experimentalist buddy in a quantum superposition or "Schrödinger cat state". All that seemed to be known for sure is that the mind of the observer is in a well-defined state ("psycho-physical parallelism" [4]). In this situation Wigner advocated a quantum collapse triggered in the experimentalist's consciousness ("consciousness as the last observer") and this understanding is known as the Wigner-von-Neumann interpretation [5].

Wigner later on changed his mind, however, when H.D. Zeh discovered decoherence ([2], see also [6–9]): the phenomenon that entanglement with the environment leads to an extremely fast suppression of interference terms/quantum superpositions. Decoherence can be understood most easily in terms of reduced density matrices ρ^{r}. If we consider the density matrix of a quantum system $\rho = |\Psi\rangle\langle\Psi|$ in the basis $|a\rangle$, the matrix element $\rho_{a'a}$ is given by the product of wave functions

$$\rho_{a'a} = \langle a'|\Psi\rangle\langle\Psi|a\rangle \equiv \psi^*(a')\psi(a) \tag{4}$$

and a total system consisting of two entangled sub-systems is described by

$$\rho_{a'b'ab} = \psi^*(a', b')\psi(a, b). \tag{5}$$

Considering now an observable acting only on the a-subsystem $L_{a'b'ab} \equiv L_{a'a}\delta_{b'b}$, one can calculate the expectation value as

$$\langle L\rangle = Tr(\rho L) = \sum_{a'b'ab} \psi^*(a', b')L_{a'a}\delta_{bb'}\psi(a, b) \equiv \sum_{a'a} \rho^{\mathrm{r}}_{a'a}L_{a'a} \tag{6}$$

with

$$\rho^{\mathrm{r}}_{a'a} = \sum_{b'} \psi^*(a', b')\psi(a, b'). \tag{7}$$

By looking only at the a-subsystem we trace out or average over the uninteresting degress of freedom of the remainder of the system. The resulting reduced density matrix ρ^{r} looks then exactly like a mixed state.

While this process provides an elegant and minimal explanation of the quantum measurement process, it also has two disturbing consequences:

- "Many Minds": the observer "splits" into multiple copies observing each possible outcome.

- Classical reality is a consequence of perspective. It results from ignoring information about the exact state of the environment. It is ”emergent”, not fundamental.

While heated debates have been fought out over the first of these points, this paper argues that the real ”elephant-in-the-room” is the second consequence: Classical reality is a consequence not only of a measurement system being coupled to an environment but also of the incomplete knowledge about this environment, which is of course a consequence of the local observer who simply cannot have all possible information about the exact state of the entire Universe. This local perspective has been dubbed ”frog perspective” (local, classical) by Tegmark and Zeh in contrast to the ”bird perspective” (non-local, quantum) in which the entire quantum system would be observed and no quantum-to-classical transition takes place: The quantum-to-classical transition is perspectival!

Thus in principle there are two possible kinds of quantum systems:

- Isolated (typically microscopic) systems with no interaction with the environment. While all quantum systems we have experience with are of this type, this is naturally always an approximation.
- The entire quantum Universe: global, encompassing, with no external environment and thus not subject to decoherence, which can be experienced only in the non-local bird perspective. It is this latter system which constitutes the only true fundamental quantum state.

As a side remark, let me mention that the quantum Universe thus has a vanishing von-Neumann entropy. It thus seems likely that the quantum Universe by itself is timeless, as described by the Wheeler-DeWitt equation [10]. It has been argued by Zeh [11] and Kiefer [12] that time itself then could be an emergent property of classical spacetime as a consequence of decoherence related to averaging out irrelevant gravitational degrees of freedom such as gravitational waves or tiny density fluctuations. In this case, not only the classical world but even time would be perspectival (compare the recent work by Rovelli [13] which argues along these lines).

The main open question of this approach seems to be what defines the ”frog perspective” or - in Tegmark's words - the ”factorization” [14] into subject, object and environment. Obviously this perspective is a consequence of the observer's consciousness being confined to her cerebral cortex. But what defines the boundaries of this ”cognitive self” without assuming a classical description and preferred basis beforehand? In the following we argue that the ”frog perspective” may be a crucial prerequisite of consciousness itself.

Of course the phenomenon of consciousness is far from being understood. In the recent years however an interesting approach called ”Integrated Information Theory” [15] has been developed by neuroscientist Giulio Tononi, which pursues a mathematical framework for evaluating the quality and quantity of consciousness based on properties of the corresponding information processing such as the irreducibility into subsets or ”integration of information”. While such a property reminds of entangled quantum systems, Max Tegmark has provided two important results which suggest that consciousness at least in the IIT framework can most probably be no quantum process:

- In [16] Tegmark estimated decoherence times of neurons and microtubules within the human brain and found that quantum superpositions decay on extremely fast time scales of the order of $10^{-13} - 10^{-19}$ seconds.
- More recently Tegmark applied IIT to quantum systems and found that due to the free choice of the Hilbert space basis only an insufficient maximum integrated information of 0.25 bits can be obtained [14].

While these results are not unchallenged, we nevertheless thus adopt as a working hypothesis that consciousness should be understood as a classical algorithm operating in the cerebral cortex and defining the factorization into subject/conscious self, object and environment. In fact, taking Tononi and Tegmark seriously, consciousness seems to be emergent itself and only possible within a classical perspective. Consciousness may actually be a by-product or even the trigger of the quantum-to-classical transition. It should be stressed here that there is not only one possible definition of ”self”. For example, biologist Francisco Varela has argued that organisms have to be understood as a ”mesh of virtual selves” [17], including the cognitive or conscious self, the immune or body self and so on. As we claim here, it is of crucial importance to understand which self or selves define(s) the local perspective giving rise to decoherence and classical reality. Indeed, situations where the various selves do not coincide seem to be particularly interesting in this regard. Apart from autoimmune diseases in which Varela was mainly interested, such situations include altered states of consciousness such as hallucinogen intoxication (for example under the influence of lysergic acid diethylamide (LSD-25)) where probands report at least from a subjective perspective a dissolution of the mental self and subjective time within a non-local experience [18]. It seems that these impressions result from a distortion of the information filtering usually proceeding within the thalamus as a consequence of the intoxication. These aspects of hallucinogen experience exhibit interesting (anti-)parallels to the adoption of the local ”frog perspective” triggering the quantum-to-classical transition: Conversely, here a classical, local self and possibly even time itself emerges, as a consequence of the neglect of information about the environment. Given these parallels it seems not to be too far-fetched to speculate whether the local algorithm constituting the conscious self gets so strongly coupled with the environment as a consequence of the hallucinogen intoxication that it is lifted to a less local perspective and in this way is able to experience some kind of ”quantum holism”. One should seriously scrutinize whether such considerations can easily be disregarded as ”New-Age-Bullshit”.

By adopting these ideas one could come to the fascinating conclusion that while the interpretation of quantum mechanics in general and the MWI in particular are notoriously difficult (if not impossible) to test in physics experiments, such tests may be possible in psychology. A simple setup could for example employ probands under the influence of LSD-25 performing quantum measurements (such as spin-up versus spin-down) on a computer screen, while an equally prepared control group deals with an equally looking interface connected to a classical simulation based on a random number generator. It is conceivable that the first group experiences quantum superpositions while the control group does not. Such a result could be understood as a strong evidence for the MWI and would dramatically affect the way we think about quantum mechanics and the quantum-to-classical transition, and even about reality itself.

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