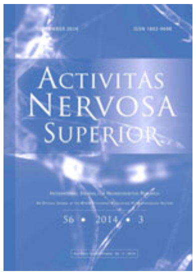

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IDEAS & PERSPECTIVES

QUANTUM THEORY OF ICONIC MEMORY

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Abstract

The undifferentiated event in the consciousness of an observer, introduced by von Neumann in his quantum theory of measurement, is elaborated to interpret experiments by which Sperling demonstrated iconic memory. The numerous quadruplets of letters known to Sperling's subjects implicitly but not consciously are interpreted as quantum states in a superposition reducible to any of its components by von Neumann's event in consciousness. The potential loss by decoherence of all information implicit in the superposition, and its possible retention by a secondary observer within the same organism, may be aspects of the biological evolution as of a precursor of the quantum computer.

Key words: *Quantum measurement; von Neuman's regress; Sperling's letter table; Superposition of quantum states; Decoherence; Quantum computer; Hidden observer; Wigner's friend; Sensory memory*

1. INTRODUCTION

Much work has been done in exploring the possible role of quantum mechanics in the functioning of the brain or of its components (Hameroff, 1998; Rosa & Faber, 2004; Bass, 1975). Here, by contrast, we interpret well established psychological observations in quantum terms without the intermediate of cerebral anatomy. In this direct link we follow up the earliest connection made between quantum mechanics and psychology in 1932 by John von Neumann in his treatment of the quantum theory of measurement (von Neumann, 1932/1955). We begin by summarising briefly his train of thought and responses to it.

The information provided by a measuring apparatus about the state of an object is typically conditional: if the object is in one of the states 01, 02, 03..., then the apparatus indicates this by having a pointer positioned at A1 or A2 or A3..., correlated in one-to-one correspondence with the states of the object. To complete the measurement it remains for the observer to note consciously the pointer position- in a step trivial classically but crucial in quantum theory.

An essential non-classical feature of quantum mechanics is that distinct states of the object may occur in a *superposition* such that several or all of them can be shown to affect the results of a suitable experiment (such as wave detection), whereas only one of the states 01, 02, 03... is found by a different experiment (such as particle detection) made on the identical object. As long as these choices are available experimentally, the superposition is said to be *coherent*.

If now the measuring apparatus is itself subject to quantum mechanics, and its states are correlated with those of the object, the pointer positions become *entangled* with the states of the

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object in a joint *object* plus *apparatus system*. The conditional statement expressing the correlation remains (if 01, then A1; if 02 then A2;…) but the states of the pointer now themselves partake in the superposition. If another apparatus is introduced in attempting to conclude the measurement, it becomes entangled in a still larger joint system. If quantum mechanics is valid universally, all matter could be drawn into this *regress* without a definite observational result.

This regress raises the question (trivial to the classical physicist): how does the measurement process conclude with a single datum (A1 or A2 or A3,…) in the consciousness of an observer? An answer requires some way of terminating the regress.

In the pragmatic, widely accepted "Copenhagen" view, quantum mechanics can be interpreted only with the aid of classically behaved (usually macroscopic) apparatus. In the esoteric *many world* view, the question is evaded by postulating that all possibilities inherent in any quantum superposition are realized, each in a different ("parallel") universe (Everett, 1957).

We adopt here the dualistic view of von Neumann (1932/1955) and Wigner (1963, 1967), who conceptualized that the regress is terminated in the consciousness of the observer (in which the outcome is lodged), whereby a unique result of the measurement is established. That event is not subject to the laws of quantum mechanics (does not obey the Schrödinger equation), except that those laws determine the probability of the outcome (pointer position). It is an event admittedly "shrouded in mystery" (Wigner, 1967) that represents contact between physics and psychology without which no measurement is completed. An event of this kind may also bring about a change in the state of motion of a physical system (Bass, 1975).

The potential rather than material existence of the states in the quantum superposition facilitates information storage and processing too extensive for material recording, such as is currently exploited in quantum computing and coding projects (DiVincenzo, 1995), and which will be central in what follows.

2. OTHER OBSERVERS

The event in consciousness which concludes a measurement is known initially only to one observer; what does it to do for other conscious observers? If these know that the observation has been completed by the first observer but are not told the result, then for them the superposition is converted into *a mixture* of the states previously superposed, now with probabilities (calculated by quantum mechanics) attached to them. These other observers' knowledge becomes that of classical physicists. For them the system must be in one of the states 01 or 02 or 03… (indicated by pointers A1 or A2 or A3…), but they do not know which one.

Can such additional observers be present in one body?

Sherrington discussed in detail the plurality of entities in anyone living body which all seem physiologically as capable of having separate minds as different bodies: "How far is the (individual) mind a collection of quasi-independent perceptual minds integrated physically in large measure by temporal concurrence of experience?" (Sherrington, 1940).

This question, placed in the present context, leads directly to an aspect of the von Neumann-Wigner view that is known as the paradox of Wigner's friend (Wigner, 1963; Bass, 1971). If some part of a central nervous system is a "quasi-independent mind" terminating von Neumann's regress by completing the measurement, then for the conscious integrated mind the object is in a mixture of states. However, if that part of the central nervous system is subject to quantum mechanics as an additional piece of apparatus, it is entangled in a joint system in a superposition which is yet to be reduced by an event in consciousness. We propose that this conundrum introduces another point of contact between quantum mechanics and psychology: the relation between Wigner's friend and Hilgard's hidden observer (Hilgard, Morgan & McDonald, 1975).

3. ICONIC MEMORY

In a revealing psychological experiment, Sperling (1960) discovered a concealed form of knowledge which can be only inferred from answers to questions chosen at the experimenter's free will. A striking illustration of that type of knowledge was given by Schrödinger (1935) in his discussion of the controversial formulation of the concept of physical reality by Einstein, Podolsky and Rosen (1935). One asks pairs of questions of a person (e.g. a student), who always answers the first question correctly but remains silent about the second question. Furthermore, it is up to the questioner which question of any pair is asked first. Should the person receive full marks for knowledge which is never expressed but merely inferred?

In Sperling's experiments a table of letters is viewed briefly (for a twentieth of second) by subjects who could then recall only four letters. However, when any particular line of the table was indicated for the subject's choice, *they recalled a group of four letters from that line,* without knowing beforehand which line would be indicated. Can we infer that the subjects, able to recall no more than one group of four letters, "knew" the entire table (full marks to Schrödinger's student)?

Sperling (1960) thus inferred the existence of an *iconic memory*, preceding the short term memory, and remarkable for its hidden capacity. If the table is a chess board, the number of distinct groups of four letters that could thus be recalled in the experiment exceeds half a million. If the table is extended to a 1000 (32x32) letters, that number is (by Stirling's approximation) 40 billion, exceeding the number of neurons in the human cortex. This steep increase, reminiscent of one of the motivations of the quantum computer by Moore's law [the increase numbers of components of transistor-based computers (Moore, 1965)], suggests that iconic memory resides in superpositions of the quadruplets of letters as quantum states, rather than in materially recorded neural states. We thus propose that evolution of organisms had long ago bettered the latest integrated-circuit technology by evolving a precursor of the quantum computer.

4. THE DURATION OF ICONIC MEMORY

A superposition of quantum states can be terminated in two ways. The first, described above, is the reduction to one of its constituent states by the event in the consciousness of an observer (von Neumann, 1932/1955; Wigner, 1967). The other occurs by the unavoidable interaction of the object with its surroundings, entangling it in a joint system ultimately so large that, for any practical purpose, it becomes indistinguishable from a mixture. The *coherence* of the states in the superposition, with all the information implicit in it, are thus lost irreversibly within a characteristic *decoherence* (or dephasing) time dependent on the quantum structure of the object and the strength of its interaction with the environment (Hameroff, 1998; Rosa & Faber, 2004). The decoherence process is a major difficulty in the realization of the quantum computer project, which depends entirely on quantum superpositions for storing and handling its materials, because any computing operations must be completed well before the onset of decoherence. Decoherence time achieved so far range from nanoseconds up to one second (Hameroff, 1998; DiVincenzo, 1995).

Sperling (1960) showed that in his experimental subjects iconic memory lasted only a fraction of a second. That time scale is consistent with iconic memory being carried by quantum superposition. In contrast to a quantum computer, the brevity of its decoherence time is a major functional advantage, since a lasting accumulation of iconic memories would present a crippling psychological burden, also regarding functional mechanisms of divided consciousness (Hilgard, Morgan & McDonald, 1975; Hilgard, 1977). It is a further advantage of the quantum hypothesis that this burden is prevented by a universal physical process rather than by a special cerebral arrangement being needed, which suggests that a functionally effective decoherence time might be included in the biological evolution of iconic memory.

5. CONCLUSION

The event terminating Von Neumann's regress had been postulated as taking place in consciousness which is introspected but otherwise unspecified. In order to make a connection with psychology more differentiation of this concept is needed.

Few of the vast number of sensory inputs and resulting iconic memories can be noted consciously. All the rest, with all their implicit information, would be lost due to decoherence unless another observer, unnoticed by the integrated consciousness, secured it in time for possible retrieval. Such a secondary observer may be postulated as Sherrington's quasi-independent mind (Sherrington, 1940), or Hilgard's hidden observer (Hilgard, Morgan & McDonald, 1975), or Wigner's friend (Wigner, 1967). The last of these is differentiated further by the alternatives of being either a quantum apparatus or a conscious observer. We know moreover, that information stored by Hilgard's hidden observer can in fact be retrieved under hypnosis (Hilgard, Morgan & McDonald, 1975; Hilgard, 1977). A misalignment of these several components of cognition may account for dissociative pathologies.

Of the iconic memories selected as quantum states from their superposition by observation, some will proceed to short-term memory, and some of these to long-term memory, by the requisite process of "attention mechanism" (Baars, 1988; Quiroga, 2012). These latter forms of memory are likely to reside in classical neuronal states rather than in quantum superpositions.

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