The Approach of Quantum Cognition to Modeling Classical Rationality Violation

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It has been well-known for decades that human behavior frequently violates the postulates of classical rationality set out in the celebrated work by von Neumann and Morgenstern (1944). The violations of classical rationality that empirical psychological research has shown in human behavior have stimulated the study of new and different approaches to modeling mental/cognitive processes based on a somehow wider concept of rationality not reliant on classical logic. Quantum cognition is a new research field emerged in the 1990s that, following an interdisciplinary approach, uses the mathematical basis of quantum theory, set out in the 1930s, among the others, by Paul Dirac (1930), John von Neumann (1932), and several fundamental concepts of quantum mechanics (i.e. superposition of states, the principle of complementarity, wave function collapse and the interference of probability, which correctly explain the results of the fundamental double-slit experiment in physics) to inspire and formalize models of cognition that aim to give an account of the empirical data collected by psychologists, with a higher explanatory power with respect to those based on traditional probability theory.

Quantum mathematical techniques have proved to be extremely effective in modeling natural phenomena at atomic and nuclear scales, and well below the nuclear level as well: the basic idea of quantum cognition is that the higher flexibility of these techniques with respect to those of classical mathematics and classical probability might be helpful in better understanding and modeling not only physical but also psychological phenomena, i.e. in a macroscopic setting which is completely different from that of quantum mechanics and concerns, for example, human perception, decision making, psychology, and also economic and social behavior.

This approach is NOT reliant on the hypothesis that there is something quantum-mechanical about the brain's processes (this is known as the quantum-mind idea), an idea which is however held, with different positions, by several well-known scholars such as Sir Roger Penrose (1989, 1994), Henry Stapp (2001, 2004, 2007), Stuart Hameroff (1998, 2007, 2012) and others. Quantum cognition does not assume the brain to be a quantum object: it only uses the mathematics of quantum mechanics, making two analogies: (*i*) the analogy between a quantum system state defined in a complex linear space (Hilbert space) and a postulated so-called 'mind state', and (*ii*) the analogy between the collapse of the wave function (quantum state) caused by the act of observing/measuring and the choice an individual makes among alternatives. The idea is that the mathematics that proved to be effective in describing the interference of wave functions in quantum mechanics, might possibly turn out to be effective also in modeling choice processes that at first glance seem to be inconsistent and are paradoxical with respect to classical rationality.

Several arguments might justify the application of quantum theory to human judgments. E.g.: judgment is not a simple read-out from a pre-existing or recorded state, but, as for the collapse of a quantum state, it is constructed from the question asked and the cognitive state created by the current context; it then follows that drawing a conclusion from one judgment changes the context which disturbs the state of the cognitive system. Changes in context and state produced by the first judgment affect the next judgment producing order effects; it follows that human judgments do not obey in general the commutative rule of classical logic: these violations sometimes lead to various types of contradictory judgments that do not observe classic probability theory. If we replace 'human quantum probability judgment' with 'physical measurement' and 'cognitive system' with 'quantum system', then the observed inconsistencies are the analogue of the points faced by physicists in the 1920s that forced them to develop the new quantum theory to explain the non-commutative findings resulting from experiments, paradoxical for classical science (Pothos and Busemeyer, 2009; Khrennikov, 2010; Busemeyer et al., 2011; Trueblood and Busemeyer, 2011). Non-commutative findings in cognitive psychology, such as order effects on human judgments, and contextual effects seem to suggest that classical probability theory is too limited to explain all aspects of human cognition. Quantum probability theory, by relaxing some of the Kolmogorov axioms of classical probability, in particular the law of total probabilities, could possibly provide a new way to account for some 'common errors' in subjective probability judgment, including conjunction and disjunction errors that in this new approach do not appear as sheer inconsistencies. So, while it is true that quantum probability has rarely been applied outside of physics, a growing number of researchers are exploring its application to human cognition, including perception (Atmanspacher, Filk and Römer, 2004), conceptual structure (Aerts and Gabora, 2005a, 2005b; Aerts, 2009), information retrieval (Van Rijsbergen, 2004), decision making (Franco, 2009; Pothos and Busemeyer, 2009), and other human judgments (Khrennikov, 2010; Busemeyer and Bruza, 2012; Haven and Khrennikov, 2013).

A simple application of quantum cognition to a choice process taken from the literature will also be given.