Anthropomorphic Quantum Darwinism as an Explanation for Classicality

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Abstract  According to Zurek, the emergence of a classical world from a quantum substrate could result from a long selection process that privileges the classical bases according to a principle of optimal information. We investigate the consequences of this principle in a simple case, when the system and the environment are two interacting scalar particles supposedly in a pure state. We show that then the classical regime corresponds to a situation for which the entanglement between the particles (the system and the environment) disappears. We describe in which circumstances this factorisability condition is fulfilled, in the case that the particles interact via position-dependent potentials, and also describe in appendix the tools necessary for understanding our results (entanglement, Bell inequalities and so on).

Keywords  Quantum Darwinism · Environment induced superselection · Entanglement

1 Introduction

Presently, it is still an open question to know whether quantum mechanics is necessary in order to describe the way that our brain functions. 1

Nevertheless, quantum mechanics is astonishingly adequate if we want to describe the material world in which we live. It is therefore natural to assume that the way we think has something to do with quantum mechanics. After all, if our worldview faithfully reflects the external world, it ought to reflect also its internal properties at the deepest level! For this reason, it is really interesting and important to reconsider epistemological questions in the

It is even an open question to know whether the non-classical aspects of quantum mechanics play a fundamental role in biological processes at all. It is for instance an open question to know whether or not quantum coherence must be invoked in order to explain intra-cellular processes. Nothing illustrates better the present situation than this quote of Wiseman and Eisert (2007): “When you have excluded the trivial, whatever remains, however, improbable, must be a good topic for a debate” . . .

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light of the most recent conceptual developments of the quantum theory. A key concept in these issues is the so-called quantum entanglement.

The term entanglement was first introduced by Schrödinger who described this as the characteristic trait of quantum mechanics, “the one that enforces its entire departure from classical lines of thought” (Schrödinger 1935). Bell’s (1965) inequalities show that when two systems are prepared in an entangled state, the knowledge of the whole cannot be reduced to the knowledge of the parts, and that to some extent the systems lose their individuality. It is only when systems are not entangled that they behave as separable systems.\(^2\) So, entanglement reintroduces holism and interdependence at a fundamental level\(^3\) and raises the following question: is it legitimate to believe in the Cartesian paradigm (the description of the whole reduces to the description of its parts), when we know that the overwhelming majority of quantum systems are entangled?

In order to tackle similar questions, that are related to the so-called measurement problem (Wheeler and Zurek 1983), Zurek (1981, 1991) developed in the framework of the decoherence approach the idea that maybe, if the world looks\(^4\) classical, this is because during the evolution, decoherence selected in the external (supposedly quantum) world the islands of stability that correspond to the minimal quantum (Shannon-von Neumann) entropy (Zurek 2003; Wikipedia: Quantum Darwinism: http://en.wikipedia.org/wiki/Quantum_Darwinism).

In the present paper, we go a step further and make the hypothesis that these classical islands (environment induced or EIN superselected Zurek 1982, 1993) would correspond to the structures that our brain naturally recognizes and identifies, and this would explain why the way we think is classical.

In the first section we make precise in which aspects our approach coincides with and departs from the standard decoherence and Quantum Darwinist approaches and what is our motivation.

In the second section and in “Appendix”, we explain the meaning of relevant concepts such as quantum entanglement, quantum bits, quantum non-locality and separability as well as Shannon-von Neumann entropy. We also present a theorem that establishes that entanglement is the corollary of interaction (Sect. 3.2) in the sense that when two systems interact, they get entangled in general. The classical situation for which no entanglement is generated during the interaction is thus exceptional.

In the third section we describe in more detail the environment induced (EIN) superselection rules approach and we apply it to the simple situation during which two quantum particles interact through a position-dependent potential, in the non-relativistic regime. We study then the classical islands that, according to the EIN selection rule, minimise the entropy of the

\(^2\) It can be shown that whenever two distant systems are in an entangled (pure) state, there exist well-chosen observables such that the associated correlations do not admit a local realist explanation, which is revealed by the violation of well-chosen Bell’s inequalities (Gisin 1991). In “Appendix” (Sect. 6.4) we treat an example in depth and explicitly derive Bell’s inequalities that are violated in that special case.

\(^3\) Holism is a rather vague concept that possesses several definitions, often mutually exclusive (Seevinck 2004). Here we mean that the quantum theory is holistic in the sense there can be a relevant difference in the whole without a difference in the parts. We provide in Sect. 6.3 an illustration of this property: the Bell states are different bipartite states for which the reduced local states (Sects. 6.5, 6.6) are the same. In this approach, entanglement, non-locality and non-separability are manifestations of holism and Quantum Weirdness, to be opposed in our view to the classical, Cartesian non-holistic approach in which the knowledge of the whole reduces to the knowledge of the parts.

\(^4\) The goal of the decoherence approach is to reconcile the first principles of the quantum theory, in particular the linearity of the quantum temporal evolution law with an objective description of the world. In the present context, when we write the world looks classical it means implicitly that we do not need an observer to let it look classical. As we explain in Sect. 2, our approach is slightly different: we want to show that the world looks classical because our eyes are blind to Quantum Weirdness.