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Quantum formalism as an optimisation procedure of information flows for physical and biological systems

Carlos Baladrón[a,*], Andrei Khrennikov[b]

[a] Departamento de Física Teórica, Atómica y Óptica, Universidad de Valladolid, 47071 Valladolid, Spain
[b] International Center for Mathematical Modeling in Physics and Cognitive Science, Linnaeus University, Växjö, Sweden

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ABSTRACT

The similarities between biological and physical systems as respectively defined in quantum information biology (QIB) and in a Darwinian approach to quantum mechanics (DAQM) have been analysed. In both theories the processing of information is a central feature characterising the systems. The analysis highlights a mutual support on the thesis contended by each theory. On the one hand, DAQM provides a physical basis that might explain the key role played by quantum information at the macroscopic level for bio-systems in QIB. On the other hand, QIB offers the possibility, acting as a macroscopic testing ground, to analyse the emergence of quantumness from classicality in the terms held by DAQM. As an added result of the comparison, a tentative definition of quantum information in terms of classical information flows has been proposed. The quantum formalism would appear from this comparative analysis between QIB and DAQM as an optimal information scheme that would maximise the stability of biological and physical systems at any scale.

1. Introduction

The inherent difficulties to quantum mechanics in order to both explain the origin of its intricate mathematical structure and connect, in a rational manner, this formalism with the results of measurements on microscopic systems or, more precisely, on systems in quantum scenarios lie at the root of the proliferation of interpretations, reconstructions and, in general, research on the foundations of quantum mechanics. A recent theory (Baladrón, 2010, 2014) on this line attempts to elicit quantum mechanics as an emergent strategy in a law-evolving Darwinian scenario in which the underlying characteristics of the physical microscopic systems −endowed with explicit capability for processing information– try to preserve reality, causality and locality as far as possible. There are other several theories that analyse the possible links between quantum mechanics and Darwinian evolution from different perspectives (Asano et al., 2015; Smolin, 2006; Zurek, 2009). In this paper, we are going to study the deep connections between the Darwinian approach to quantum mechanics (DAQM) (Baladrón, 2010, 2014) and quantum information biology (QIB) (Asano et al., 2014, 2015) −a new theory that applies the quantum formalism to the dynamics of information in biological systems–.

Darwinian evolution by natural selection constitutes one of the major achievements of science. It explains the evolution of life from a common origin to the diversity of complex multicellular systems. Schematically, Darwinian evolution is based on three properties of biological systems: variation, selection, and inheritance. An enhanced rate of survival −selection– of those organisms whose randomly mutant genetic code −variation– presents comparative advantages within a certain environment brings about an increase in the frequency of the positive trait among the offspring of the next generation −inheritance–.

The open discussion recently aroused in biology about the role played by complementary or alternative mechanisms of evolution to those propound by Darwinism and an outline of its translation and unified modeling in QIB are addressed in Appendix B.

Randomness is the main underlying element driving the self-development of the biosphere. But randomness is also a central characteristic of quantum mechanics, at least in the majority of its interpretations. Another basic common trait shared by biological Darwinism and quantum mechanics is the central role played by information. Is the joint presence of these two fundamental properties, randomness and information, enough evidence to consider the existence of a general mechanism underlying both theories? In this paper, we explore the possibility that this general mech-

* Corresponding author.
E-mail addresses: baladron@cpd.uva.es (C. Baladrón), andrei.khrennikov@lnu.se (A. Khrennikov).

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anism, common to biology and physics, is Darwinian evolution, and that this mechanism tends to select those systems that present quantum behaviour because it would imply the optimisation in a certain environment of the information flows for the systems, as much in physics as in biology, and this would maximise the fitness function of these systems. Certain studies (Chatterjee et al., 2013; Frank, 2009) carried out in the field of evolutionary biology strongly support this conclusion.

In Section 2 a brief Description of DAQM and its tenets are outlined. A schematic portrayal of QIB is drawn in Section 3. The main results of the comparison between both theories are discussed in Section 4. The conclusions are presented in Section 5. A more detailed analysis of DAQM is developed in Appendix A. Finally, the interrelation of Darwinian and Lamarckian evolutionary scenarios and their quantum-like modeling is considered in Appendix B.

2. Darwinian approach to quantum mechanics (DAQM)

We are going to outline a Darwinian scheme for fundamental physical systems, that has been already preliminarily discussed (Baladrón, 2010, 2014). Such a scheme tries to explain the emergence of quantum mechanics in the physical world –a hypothesized law-evolving physical world– as an evolutionarily stable strategy (ESS), i.e. roughly speaking, as a conditional local maximum of a fitness function defined in the overarching framework of an abstract landscape of all possible algorithms. In this approach, every fundamental system in the physical world is supplemented with a probabilistic classical Turing machine (see Encyclopedia of Mathematics, 2013. Turing machine) –basically an abstract computer with a randomiser– within a methodological information space. There are no universal laws, but every system is governed by the algorithm written on its probabilistic classical Turing machine.

It might seem radical to ground Darwinian evolution mainly on algorithmic information, however the initial development of molecular biology was indirectly related (Chaitin, 2012) to the foundational paper of Turing on computer science (Turing, 1936). In fact, the identification process of the DNA informational function in biology was deeply influenced by the Turing machine concept, to the point that probably there had not been possible to recognize the role of DNA as software in molecular biology before the work of Turing (Chaitin, 2012).

The incorporation of the probabilistic classical Turing machine to the constitution of the fundamental system in our Darwinian approach represents a move in the direction of testing the possibility that matter be complex. But this trend is not original, rather it was started at the dawn of quantum mechanics when the state of a microscopic system was characterised by a wave function. In fact, the Turing machine might be considered a generalization of the wave function that in turn in certain interpretations of quantum mechanics is viewed not as a mere description of the quantum state of the system, but as a part of the physical law that determines the behaviour of the system (Baladrón, 2014; Goldstein, 2010).

The main role played by the probabilistic classical Turing machine associated with the bare fundamental particle, in addition to constitute the basic tool in the law-evolving mechanism as aforementioned, is to expose the flows of information in the physical systems. Thus, bare matter and information form the indivisible pair that shapes the character of physical systems. This relevance of information in the Darwinian approach brings closer this development to the quantum information standpoint on quantum mechanics (Brukner and Zeilinger, 1999; Caves et al., 2002; D' Ariano, 2007; Summhammer, 1994).

All physical systems in DAQM are receivers of information, and this information consists of the dynamical parameters of the receiver's surrounding systems (Baladrón, 2014).

The picture of interconnection between the physical and information worlds which is explored in our paper is very close to the views of J. Wheeler (1990), we cite his informational physics manifesto:

"It from bit. Otherwise put, every 'it'—every particle, every field of force, even the space-time continuum itself—derives its function, its meaning, its very existence entirely — even if in some contexts indirectly — from the apparatus-elicited answers to yes-or-no questions, binary choices, bits. 'It from bit' symbolizes the idea that every item of the physical world has at bottom – a very deep bottom, in most instances – an immaterial source and explanation; that which we call reality arises in the last analysis from the posing of yes–no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and that this is a participatory universe."

The information representation is mathematically based on long sequences of zeros/ones. In our model these sequences are processed by Turing machines associated with physical systems.

We also cite Chalmers comment on Wheeler's statement:

"Wheeler (1990) *has suggested that information is fundamental to the physics of the universe. According to this 'it from bit' doctrine, the laws of physics can be cast in terms of information, postulating different states that give rise to different effects without actually saying what those states are. It is only their position in an information space that counts."*

In the Darwinian approach, every fundamental system can be considered as a microscopic agent in which the algorithm stored in its Turing machine plays the role, in a biological analogy, of its genotype, and the wave function calculated by means of the algorithm, taking into account the interaction with the environment, acts as the phenotype of the physical system, i.e. the observable expression of the system's genotype. But the reference to biology can be considered more than an analogy. As previously mentioned, we contend that both fields –quantum mechanics and biology– might share the same generalized Darwinian structure (Aldrich et al., 2008) for the informational substrate under their specific material realization.

Random mutations, the key mechanism of variation in Darwinian evolution would correspond in DAQM to read/write errors during the execution of the programme in the probabilistic classical Turing machine, as in usual digital computers. Therefore, the read/write error rate in the information space would constitute a parameter of the theory (Baladrón, 2014).

According to this Darwinian scheme, the present quantum algorithms would be the result of Darwinian evolution under natural selection acting on physical systems that are endowed with a probabilistic classical Turing machine (see Appendix A). The quantum behaviour induced by those algorithms would constitute an ESS. This means that quantum mechanics would be an attractor in the abstract landscape of all possible algorithms, and therefore it would represent a robust strategy for microscopic systems that might be achieved following different pathways and starting in different initial points. At time $t = 0$ the system would be fully governed by the randomiser. There would not be any information stored on the tape of the probabilistic classical Turing machine besides the defining set of elements and operations supplemented with basic instructions ensuring both that the initial control of the system is exerted by the randomiser and that the information received by the system is stored giving rise to the gradual development of a programme that progressively takes over control of the system.

Therefore the optimisation of information flows for systems endowed with a probabilistic classical Turing machine would constitute an ESS (see Appendix A.2) and plausibly imply (see Appendix A.3) the quantum mechanical postulates –in particular the com-