Quantization, spatiotemporalization and pure variation

Jérôme Rosanvallon
(PhD student, Université Paris Diderot; Haredhol, Centre Cavaillès, ENS)

Frontiers of Fundamental Physics 14, "Epistemology and Philosophy"
16 July 2014
Introduction

This presentation aims to show, with pure conceptual tools called by mathematical formalism, physical experiments and metaphysical constraints, that quantum systems don’t have only strange spatiotemporal properties on a classical/relativistic space-time background, i.e. Minkowski spacetime (as it is commonly presented on the basis of Quantum Field Theory). Their spatiotemporal properties would be more deeply only extrinsic, secondary, relative to a reference frame, i.e. a classical observer; indeed, intrinsically, they wouldn’t "live" in space-time: "Physicists are mistaken when they try inscribing quantum variability in the course of time" (Connes et al., The Quantum Theater, 2013).

In that aim, we will first propose a both realistic and relationalist interpretation of quantum formalism and we will then secondly tend to inscribe it in a generalized Darwinian way of understanding not only the decoherence process but the whole physical reality: fields and their constitutive invariants would only be selected mixtures between quantum and space-time reality.

Outline

I. Physical reality and absolute objectivity of quantum formalism.
II. "Quantum Darwinism"? Generalizing the Darwinian model to the whole physical reality.
I – Physical reality and absolute objectivity of quantum formalism

1.1 Quantum formalism can be understood in a realistic way without assuming any other world (superposition principle, indeterminacy principle, randomness).

1.2 Quantum experiment can be understood in a relational way without assuming any subjective determination (implicit frames of reference in quantum physics).
1.1 Quantum formalism can be understood in a realistic way without assuming any other world.

A realistic view of quantum formalism is unavoidable for the simple reason that quantum phenomena and principles have real physical effects: interference fringes and qubits (superposition principle), vacuum fluctuations (indeterminacy principle), etc. But what quantum formalism, i.e. Hilbert or Fock space, imply to be real? Only two fundamental things: states of variation (state vectors) and variables (operators).
Ontological furniture of quantum formalism: 1/ state vector (= state of variation)

• First, a quantum object is intrinsically not a particle nor a wave in space-time. Therefore any attempt to maintain these classical determinations by mixing them (as Bohr’s complementary principle or Bohm-De Broglie’s pilot wave) is worthless. A quantum object is intrinsically nothing else than a state vector in a Hilbert space or a Fock space (i.e. an infinite sum of tensor products of Hilbert spaces introduced when the number of quantum objects itself is treated as a variable or operator).

• Second, this state vector must neither be reduced to wavefunction. Wavefunction, strictly speaking, is only the state vector whose variable, i.e. what forms basis states that are transformed at each instant, is the operator position. Therefore it supplies a spatiotemporal identification of the quantum object, ensuring, with the normalization condition, that if this variable is measured, this object would indeed be somewhere. But in fact position is just a variable among others with no ontological precedence (only a quantum order of determination like any other variable).
Ontological furniture of quantum formalism: 1/ state vector (= state of variation)

• Third, a state vector is not a mere predictive probabilistic mathematical tool: it determines not only the amplitude probabilities of the possible states of a variable of a quantum system attending to be measured, but also the real superposed states of this variable including all their virtual superpositions, i.e. all the (finite or infinite) possible linear combinations of its basis states. Before any destructive measurement, a quantum state is therefore in the same time in all the states it can be - even if these states constitute determinations that are classically contradictory: being simultaneously here and there (according to variable position), up and down (according to spin angular momentum), 1, 2 and n (according to variable number), etc.

• "Ghostly" or "virtual" effects are terms generally used to designate interference or fluctuations effects of superposition or indeterminacy principles. In fact "virtual" is not philosophically the opposite of "real" but of "actual". And "actual" means only "durable", i.e. inscribed in a material duration and thus in the (derived) course of time.
Ontological furniture of quantum formalism: 2/ operator (= variable)

• What are the conditions that constrain any quantum state of variation? First, some classical conditions: initial conditions (experimental preparation), time evolution according to the principe of least action (Schrödinger equation), determined reality of a final result (normalization condition). But also two purely quantum conditions:
  1/ real/virtual superpositions of all the possible states of a variable
  2/ order of variables or operators applied on basis states of the state vector.

• Non commutativity of operators is indeed the second determining fact of quantum reality. It determines the objective (in)determinability of conjugate variables (indeterminacy principle). To formulate naively what encodes mathematically non-commutative geometry (or even symplectic manifold), there seems to have a partial quantum order of variables. This partial ordering, where quantum fluctuations come from, determines a kind of "acausal structure" opposed to causal structure determined by partial spacetime order of states of variation (light-, space- and time-like vectors).
Many-worlds realism as double unrealistic refusal

• Why a realistic view of the state vector (even reduced to wavefunction) would lead to assume other worlds created at each measure and even each moment (Everett interpretation)? Because of the two underlying consequences of the "wavefunction collapse", or projection of the vector state on one of the eigenstates of a given basis:

  • **1/ selective role of environment** (experimental measurement being just an environment as objective as any classical reality with which quantum system interacts). Now *decoherence theory* perfectly admits and explores this selective role – Zurek, co-founder of this theory even speaking of "quantum Darwinism".

  • **2/ irreducible randomness.** If *decoherence* explains the *temporal* loss of superposition effects, it doesn’t explain the *sudden* loss of unitarity produced by *measurement*: why this particular outcome and not another? If the value allocation of a quantum variable is relative to environment, it does not prevent that randomness is intrinsic to our world.
1.2 Quantum experiment can be understood in a relational way without assuming any subjective determination.

A relational view of quantum formalism is unavoidable for the simple reason that every physical theory necessarily consider variables and states of variation of a system relatively to a reference frame whose arbitrary character has to be lifted (relativity principle). But which kind(s) of objective reference frame underlie quantum experiments and are implied by quantum formalism?
What does any frame of reference imply? Classicality!

• Decoherence theory and experiments now explore deeply the transition between quantum and classical reality, blurring their common limit: \textit{where ends quantum reality and where begins classical reality}? Is it a simple question of space or, rather, time scale? Thus the limit between quantum and classical seems as necessary as arbitrary: this is the old problem of "Heisenberg cut".

• \textbf{Classicality could proceed of the implicit introduction}, not only of a (subjective) observer, but more deeply and generally of an objective frame of reference used to consider a quantum system. Such a frame of reference implies \textbf{not only} space-time coordinates, i.e. \textit{spatiotemporal localization}, but more fundamentally, for each variable, \textbf{allocation of a value exclusive of any other}: here lies perhaps the distinction between destructive and non destructive measurement. In the last case, \textit{states of variation} cease to be superposed and \textbf{become partially ordered} while variables cease to be partially ordered and \textbf{become "superposed"} for any given state of variation.
Does it exist also pure intrinsically quantum frame of reference?

• A fundamental distinction has to be made between "exo-reference" and "endo-reference" (Deleuze and Guattari, *What is Philosophy?*, 1991). It seems to be an obvious distinction for physicists: exo-reference would be what is subject to spatio-temporal symmetries (Poincaré group, diffeomorphisms) as endo-reference would only be subject to internal symmetries (gauge theories). But endo-reference must refer not only to the spatiotemporal interaction of quantum objects but to a pure quantum point of view, i.e. to the fact that every quantum object (state vector) can serve as reference to describe every other one and, de jure, all the other ones.

• The physical translation of this endo-reference is the tensor product of Hilbert spaces that explains all entanglement effects and determines quantum reality as intrinsically nonlocal and nonseparable. Results of these tensor products (on n possible localized particles) are purely independent of classical or relativistic space-time, as it is perfectly showed by "EPR-like" and "delayed choice" experiments.
12

CLASSICAL REALITY

Schrödinger equation (unitary evolution)

coherent states (superposition principle)

partially ordered variables (indeterminacy principle)

loss of superposition (decoherence)

allocation of a determined value (random collapse)

classical environment of the quantum system

system prepared, i.e. arbitrarily separated

tensor product of Hilbert spaces (entangled systems)

QS (Quantum System)
II – "Quantum Darwinism"? Generalizing the Darwinian model to the whole physical reality

2.1 The Darwinian model of explanation: primacy of variation, selection as substraction, independence of two levels (one selecting blind variation of the other).

2.2 Fields as double result of a selective process: quantum fields selected from quantum reality by relativistic/classical space-time, gravitational field selected from quantum reality by relativistic/classical matter.
2.1 The Darwinian model of explanation

*On the Origin of the Species* constitute not only a scientific revolution of biology but a revolution of science itself, i.e. of its classical model of explanation. This new model involves three fundamental aspects: explaining invariant from variation, understanding production of reality as a selective process, distinguishing two independent levels, one selecting the variation that constitutes the other.
Primacy of variation

• Darwin has been the first scientific to take as point of departure the fact of variation without trying to explain it (see the title of his book, Variation of Animals and Plants..., and of the first two chapters of his masterwork). Classical model of scientific explanation (since Aristotle, Galileo, etc.) and especially others models of biological explanation (fixism, transformism, or even evolutionnism - towards individuality, freedom, complexity, etc.) have always tended to explain variation from (initial or final) invariant. At contrary, for Darwin, what has to be explained, given the incessant and infinite variation of the living, are its apparent and temporary invariances, i.e. origin of the species - what natural selection is at stake.

• Recognizing this primacy of variation is the first implicit meaning of "quantum Darwinism" program. Superposition of states and indeterminacy of variables or quantum fluctuations (two fundamental quantum aspects of variation) are taken as real points of departure from which classical reality must be understood.
Selection as substractive process

- Recognizing the production of (classical) reality as a result of a selective process is the second implicit meaning of "quantum Darwinism" program: decoherence is nothing else than an automatic process of substraction/reduction/removal (exactly opposed to process of addition implied by any emergent theory: emergence is anti-Darwinian).

- But here lies a huge problem. In the living (i.e. the organic stratum), selection means reproduction, selective constraints are constraints of reproduction: what has been selected is simply what has been until now reproduced (in all possible and first purely molecular ways). But what about the physical stratum? In order to be selected, i.e. to maintain themselves, constitutive process of physical stratum don’t have to reproduce variable copies of themselves, they just have to produce the most durable effects as possible, i.e. histories or durations allowing themselves that other durations are produced and so on (the Big Bang story). Thus selective process must be able to explain history (the origin of time) rather than merely explain from/by history (time as datum).

Generalized Darwinian model
Independence of two levels

• However, "quantum Darwinism" program needs a third meaning to be actually coherent with the Darwinian model: natural selection requires two independent levels, a first level that varies independently of the other and a second one that selects afterwards and extrinsically the first one (for ex: individual variations and resources of environment in the case of the seminal Darwinian theory – but it also works with other pairs of levels independent of each other in the organic stratum).

• Consequently, no Darwinism can be effective in the physical stratum if we don’t have, from the beginning, two independent levels or irreducible sides of reality, one selecting variation that constitute the other. Classical reality cannot be simply deduce from the sole quantum reality through a selective process. If quantum reality actually stands for what is selected (i.e. the level of variation) and classical reality for what results from this selection, what operates the selection (i.e. the level of selection) still lacks in this view.

Generalized Darwinian model
2.2 Fields as double result of a selective process

If quantum reality is intrinsically independent of space-time, then quantum fields are necessarily a derived mixture of these two fundamental sides of reality. But what explains this mixture? A first selective process: superselection rules determining distinct fields and relativistic causal order organizing their interaction. Could gravitational field not be another mixture, selecting classical space-time from pure quantum background?
A Darwinian overview of Quantum Field Theory

• One day maybe someone will decide to write a book called *On the Origin of Quantum Fields*, summarizing physical theories and discoveries of the 20th and 21st centuries founded on Quantum Field Theory and constituting the Standard Model. But how could we explain this origin? From which selective process?

• It is not sufficient to account for the origin of distinct quantum fields by a series of spontaneous symmetry breakings (chiral symmetry, Higgs mechanism, CPT or matter/anti-matter symmetry) and superselection rules of which come intrinsic or semi-extrinsic properties (mass, charge, spin-statistics relation) producing distinct interacting fields and fields of interaction. We must first account for the origin of quantum field itself, i.e. the possibility of local and separable quantum interactions from non local and entangled quantum reality (operators localization and path integral formulation).

• What operates the selection, i.e. explains this double origin is the history of classical space: the advent of a partial order structure, its original inflation and then accelerating expansion. In this case, classical space-time does select quantum "materialization".
A Darwinian overview of Loop Quantum Gravity

• One day the same (or another one) could decide to write another book called *On the Origin of Gravitational Field*, founded not only on General Relativity but also on an perhaps achieved Quantum Theory of Gravity that could account for the Lambda-CDM Model (and its own symmetry breakings?). Would the same selective process be able to explain origin of gravitation or do we need another parallel selective process?

• The idea (inherited from GR) that any QTG must be "background independent" simply means that such a theory must precisely generate any space-time background – and can’t merely, like string theory, let another quantum field, gravitational one, emerge (due to superselection rules) from a classical background (even if it is n-dimensional). **But generating from what? Pure quantum background**, shows LQG, remains necessary: something like quantized states of "localizability" (spin networks) before any ordering.

• But what explains, from this quantum "localizability", the origin of smooth and partially ordered manifold, its gravitational constant and dynamical curvature, could it be the manifold itself? **Classical matter i.e. material durations/histories play the selective role.**

Generalized Darwinian model
How could we unify these two mixtures?

• We have seen that **variables and states of variation**, the ones being superposed when the others are partially ordered, **constitute the only ontological furniture underlying quantized reality as well as spatiotemporalized reality**.

• Materialized, localized and causal things and states of things (fields, particles, waves, etc.) are the mere results of a **double selective process** ruled by these two fundamental sides of reality: **classical spatiotemporality selects quantum reality** (as virtual "materialization") **to finally produce quantum and classical materiality** (= quantum fields) **while classical materiality selects quantum reality** (as pure "localizability") **to finally produce classical spatiotemporality** (= gravitational field).

• Though closely linked, the two processes are intrinsically independent: it is perhaps what explains that **no physical unification of all fields is theoretically possible** – unless physicists bring it upstream, trying rather to **unify the two fundamental components of these derived mixtures**.

Generalized Darwinian model 21
The upstream idea of pure variation

- Following Darwin’s first principle (primacy of variation), **double physical distinction in variables and states of variation must result from a pure variation**. If all invariant (any constant, symmetry, equation, durable thing, etc.) has to be explained by a selective process, **finite number of distinct variables and of distinct states of variation are the first invariants** that have to (producing quantum and/or space-time reality).

- Pure variation means variation 1/ **without subject (something, etc.) that varies**, 2/ **without space-time inside which it varies**, 3/ **without any other limit than the infinite or infinitely infinite** (infinite dimensionality, spectra of values and speed of variation), 4/ **without other necessity than the fact that it varies** (pure contingency and randomness).

- Only a generalized Darwinian model could afford a limitating factor, i.e. a selective constraint explaining the appearance of "fine-tuned" constants and invariances (what multiverse theories are at stake). In our view, this constraint can only be **subsistence, in all possible ways, that results in the multiplication of superposed material durations**.