# Classical selection and quantum Darwinism

The quantum Darwinism approach offered by Wojciech Zurek (PHYSICS TODAY, October 2014, page 44) is based on a quantum "credo" embedded in the usual mathematical postulates of quantum mechanics: A quantum state is a vector in a Hilbert space, it undergoes a unitary evolution, and composite systems are described by tensor products that allow entangled states. In what may be a hint at something else, Zurek adds a repeatability postulate stating that an immediately repeated measurement yields the same outcome. He justifies the postulate with the argument that "classical repeatability is a given: Measurements reveal classical states, so repeatability follows from their objective existence. . . . Repeatability is key for the very idea of a state as a predictive tool: The simplest prediction is that a state is what it is." Then Zurek's goal is to deduce the usual next "postulates" of quantum mechanics, the so-called collapse postulate and Born's rule.

In our opinion, the main trouble with his (quite respectable) attempt is that it starts from a purely mathematical credo: Vectors in a Hilbert space come directly from the sky, and you must believe in them to reach enlightenment. That approach may not be the best to reach physical conclusions, and before one speaks about vectors in a Hilbert space, some physics may be required to specify what the "state" really is.

As we have discussed in our work,[1,2] such a "quantum state without mathematics," which we call a modality, has a very specific feature: It does not belong to a system, as it would in classical physics, but jointly to the system and to its context—the arrangement of experimental equipment that gives access to the system. And in a given context, such a modality is indeed certain and repeatable—that is, it is real and objective. Perhaps that is what Zurek actually means when he writes, "A state is what it is." We offer a simple example: A photon does not "have" a polarization at 45°, but it will be transmitted with certainty (a property of the system) through a polarizer oriented at 45° (a property of the context).

Such thinking will not invalidate Zurek's arguments, but it will turn them on their heads: The credo actually already contains the conclusion he wants to reach—that the experiments must be defined classically; without that, a quantum state has no meaning.[2] Therefore, the PHYSICS TODAY article does not explain, as Zurek says, "why we experience our world as classical." Rather, it shows—remarkably—that quantum mechanics is a consistent theory.

## References


1. P. Grangier, *Eur. J. Phys.* **23**, 331 (2002).
2. A. Auffèves, P. Grangier, http://arxiv.org/abs/1409.2120.



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**This short letter** in response to Wojciech Zurek's article "Quantum Darwinism, classical reality, and the randomness of quantum jumps" points out extant rebuttals in the literature to some of the author's key claims.

On the first page of his arXiv.org version of the PHYSICS TODAY article (http://arxiv.org/abs/1412.5206), Zurek states that

> decoherence selects preferred pointer states that survive interaction with the environment. They are localized and effectively classical. They persist while their superpositions decohere. Decoherence marks the border between quantum and classical, alleviating concern about flagrant . . . manifestations of quantumness in the macroscopic domain.
>
> Here we consider emergence of "the classical" starting at a more fundamental pre-decoherence level, tracing the origin of preferred pointer states.

However, the idea that preferred pointer states naturally "emerge" from the quantum level has been refuted in the literature, in particular in a paper[1] showing that "classical" pointer states do not emerge unless a key aspect of classicality has been tacitly assumed from the beginning. In other words, the "quantum Darwinism" program is fatally circular.

The assumption generating the circularity usually takes the form of a predesignated system that is considered separable from its environment (the same assumption appears in the discussion about information flow in Zurek's article). The system acquires decohered observable (or stable) states because it is presumed to be distinguishable from a designated set of environmental subsystems, all assumed as having random phases—with respect to each other and the system. The only correlations between the system and the environmental subsystems are assumed to be established via the designated Hamiltonians.

However, in the absence of this sort of predesignated partitioning of all degrees of freedom into the system and its surroundings—measurement apparatus, environment, and so forth—where the initial phase of each subsystem is random, the desired decoherence and emergence of pointer states, or einselection, do not follow. The partitioning is inevitably based on what a human observer would be able to identify and measure, such as distinguishable atoms and molecules, so the account is dependent on assuming the classical realm of the observer.

The need for this pre-partitioning fatally conflicts with the claim that classicality emerges naturally from the quantum realm: Absent a pre-partitioning of all degrees of freedom into uncorrelated systems of interest, classical pointer states do not emerge. With unitary-only dynamics (lacking nonunitary collapse), the quantum realm does not have any *a priori* preference for the assumed uncorrelated degrees of freedom. On the contrary, a unitary-only evolution would typically begin with a maximally entangled universal state.

As I noted in reference 1, one can observe the decoherence process experimentally, but that observation does not demonstrate that einselection occurs in a unitary-only dynamics or that classicality emerges in such a dynamics. A