Can Classical Worlds Emerge from Parallel Quantum Universes?

Simulations deliver hints on how the multiverse produced according to the many-worlds interpretation of quantum mechanics might be compatible with our stable, classical Universe.

By **Michael J. W. Hall**

We understand quantum mechanics well enough to make stunningly accurate predictions, ranging from atomic spectra to the structure of neutron stars, and to successfully exploit these predictions in devices such as lasers, MRI machines, and tunneling microscopes. Yet there is no generally accepted explanation of how the solid reality of such devices—or of objects such as cats, moons, and people—arise from a nebulous quantum wave in an abstract mathematical space. Some physicists prefer to ignore the problem, suggesting that we should just "shut up and calculate!" Others seek answers by modifying quantum theory in various ways or by searching for ways to explain how stable structures can emerge from quantum theory itself. Taking the latter approach, Philipp Strasberg and colleagues at the Autonomous University of Barcelona in Spain use simulations to show that, on large scales, a robust reality with classical features can emerge for a broad class of quantum systems, independently of their detailed microstructure [**1**]. Their conclusion suggests how the emergence of our classical world can be explained in the context of the "many-worlds interpretation" of quantum mechanics, in which countless parallel worlds branch off from each other each time a measurement is performed. Loosely speaking, the idea is that large-scale classical features emerge from underlying quantum dynamics much like the stable macroscopic jets of a garden sprinkler emerge from the countless microscopic tumbling trajectories of individual water molecules (Fig. **1**). The results have broad potential implications, ranging from cosmology to statistical mechanics.

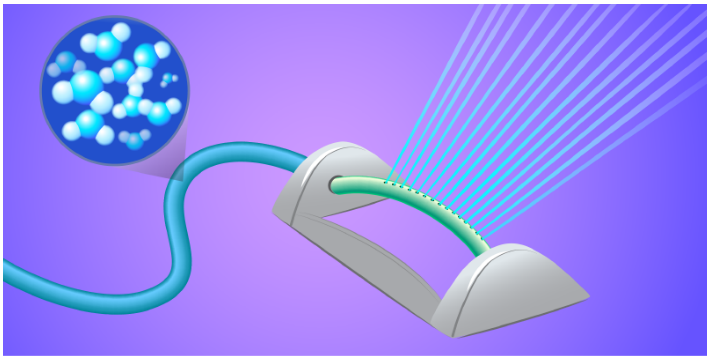

Figure 1: Like a set of sprinkler jets emerging from countless quantum particles, a set of worlds with classical features might naturally emerge from a complex quantum system, according to simulations based on the "many-worlds interpretation" of quantum mechanics.
Credit: APS/Carin Cain

The famous paradox of Schrödinger's cat is about amplifying a quantum effect—a radioactive atom that has both decayed and not decayed—into a large-scale effect—a cat that is both dead and alive. But we don't see such cats. More generally, the world around us consists of stable objects with properties well described by classical physics. Yet these stable objects are made up of many microscale systems governed by quantum physics. How do we reconcile these two pictures?

One convenient approach to do so postulates two types of quantum dynamics: The first is the Schrödinger equation, which governs the evolution of the quantum wave function of an isolated quantum system; the second is a collapse of this wave function occurring when the system interacts with a classical system. But while useful for calculations, this approach merely presupposes a quantum–classical distinction without explaining it. More sophisticated approaches instead suggest that the Schrödinger equation itself should be modified, tweaking it in a way that causes the wave function to collapse about the center of mass of any given object. To date, however, approaches based on such modifications have not been supported by experiments [**2**].

A different approach is to explain the emergence of a classical world as an inherent consequence of the Schrödinger equation itself. In the many-worlds interpretation, for example, this equation is understood as describing a set of parallel worlds that continually branch out into new worlds as a result of quantum events [**3**]. Schrödinger's cat is always either dead or alive in each world, according to whether the atom has decayed or not decayed in that world. The promise of this approach is to unify quantum evolution and our perceived reality: Everything is quantum on the smallest and largest scales, with no need for modified dynamics or wave-function collapses. However, many physicists are not convinced that this promise has been fulfilled: How does the constant branching of worlds lead to the persistent reality of cats, moons, and people rather than to a thoroughly chaotic randomness?

Strasberg and his collaborators tackle this question in a novel way. Much previous work connects the answer to the idea of environment-induced decoherence, whereby stable objects arise from interactions of the many components of a quantum system with their external environment [**4**]. These interactions effectively hide quantum interference effects deep within many far-flung environmental degrees of freedom, making them impossible to observe in practice. However, this approach suffers from a problematic fine-tuning, meaning that it only works well for specific types of interactions and initial wave functions. What's more, it has typically only been investigated for extremely simplified models. In contrast, Strasberg and colleagues show that, for a wide range of possible evolutions of a wave function with many energy levels, a self-consistent set of stable features emerges at observable coarse-grained scales. Further, their model doesn't require fine-tuning: These features are robust to the choice of initial conditions and to the details of the interactions between energy levels at small scales.

To achieve their result, the researchers take advantage of the tremendous power of modern computers to simulate quantum evolution up to an impressive 50,000 energy levels. Such a number is still modest compared to what would be needed to simulate everyday classical phenomena but is still significant compared to previous simulations on much simpler systems. The team considers a broad range of coupling strengths and initial wave functions (randomly selected within particular classes of evolutions described by Hamiltonians with the same broad form). Their results show that, irrespective of these choices, approximately the same large-scale structure of stable branchings emerges. This conclusion, obtained without appealing to an external environment or to fine-tuning, supports the idea that our classical reality is able to pull itself up by its bootstraps from a purely quantum substrate.

The results are relevant to understanding the mysterious quantum–classical distinction and introduce an innovative *ab initio* numerical approach that could pave the way to solving some perceived shortcomings of the many-worlds interpretation. But the work also relates to ideas from statistical mechanics, including attempts to explain the emergence of an arrow of time in our Universe. For instance, the researchers interpret their main result (the emergence of a stable and slowly evolving macroscopic structure) as arising from an inherent randomization of quantum phases at the microscale—similar to how, in classical statistical mechanics, macroscopic features such as pressure and temperature arise from nonintegrable or chaotic microscopic motion. They also show that, for the class of evolutions that they consider, some branchings lead to worlds in which entropy generally increases, as in our Universe, and some in which it generally decreases—which would lead to two classes of worlds with opposite entropic arrows of time. Interestingly, these worlds would be part of one overarching multiverse in which time symmetry is globally respected.

The results don't solve all outstanding questions about the many-worlds interpretation and its need for countless worlds and branches to explain the single world that we experience. For example, the researchers show that there is a stable set of worlds and branchings, but they don't demonstrate that this set is unique (although they qualitatively argue that this is likely the case). And they can't explain why we experience laws such as the conservation of energy or the Born rule—which dictates the probability that a measurement on a quantum system will have a certain outcome—in the single branch of the multiverse that we have access to (our world). Recent work by two researchers from the team suggests that an approach similar to the one pursued here can shed some light on the latter issue [**5**]. Clearly, more work is needed to make progress on these fronts.

Michael J. W. Hall: Department of Theoretical Physics, Research School of Physics, Australian National University, Canberra, Australia

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