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Natural selection acts on the quantum world

Philip Ball

Objective reality may owe its existence to a 'darwinian' process that advertises certain quantum states.

A team of physicists has proved a theorem that explains how our objective, common reality emerges from the subtle and sensitive quantum world.

If observing the world tends to change it, how come we all see the same butterfly?

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If, as quantum mechanics says, observing the world tends to change it, how is it that we can agree on anything at all? Why doesn't each person leave a slightly different version of the world for the next person to find?

Because, say the researchers, certain special states of a system are promoted above others by a quantum form of natural selection, which they call quantum darwinism. Information about these states proliferates and gets imprinted on the environment. So observers coming along and looking at the environment in order to get a picture of the world tend to see the same 'preferred' states.

If it wasn't for quantum darwinism, the researchers suggest in *Physical Review Letters*[1], the world would be very unpredictable: different people might see very different versions of it. Life itself would then be hard to conduct, because we would not be able to obtain reliable information about our surroundings... it would typically conflict with what others were experiencing.

Taking stock

The difficulty arises because directly finding out something about a quantum system by making a measurement inevitably disturbs it. "After a measurement," say Wojciech Zurek at Los Alamos National Laboratory in New Mexico and his colleagues, "the state will be what the observer finds out it is, but not, in general, what it was before."

> **"They survive monitoring by the environment to leave 'descendants' that inherit their properties."**
>
> Wojciech Zure
> Physicist, Los Alamos National Laboratory in New Mexico

Because, as Zurek says, "the Universe is quantum to the core," this property seems to undermine the notion of an objective reality. In this type of situation, every tourist who gazed at Buckingham Palace would change the arrangement of the building's windows, say, merely by the act of looking, so that subsequent tourists would see something slightly different.

Yet that clearly isn't what happens. This sensitivity to observation at the quantum level (which Albert Einstein famously compared to God constructing the quantum world by throwing dice to decide its state) seems to go away at the everyday, macroscopic level. "God plays dice on a quantum level quite willingly," says Zurek, "but, somehow, when the bets become macroscopic he is more reluctant to gamble." How does that happen?

Quantum mush

The Los Alamos team define a property of a system as 'objective', if that property is simultaneously evident to many observers who can find out about it without knowing exactly what they are looking for and without agreeing in advance how they'll look for it.

Physicists agree that the macroscopic or classical world (which seems to have a single, 'objective' state) emerges from the quantum world of many possible states through a phenomenon called decoherence, according to which interactions between the quantum states of the system of interest and its environment serve to 'collapse' those states into a single outcome. But this process of decoherence still isn't fully understood.

"Decoherence selects out of the quantum 'mush' states that are stable, that can withstand the scrutiny of the environment without getting perturbed," says Zurek. These special states are called 'pointer states', and although they are still quantum states, they turn out to look like classical ones. For example, objects in pointer states seem to occupy a well-defined position, rather than being smeared out in space.

The traditional approach to decoherence, says Zurek, was based on the idea that the perturbation of a quantum system by the environment eliminates all but the stable pointer states, which an observer can then probe directly. But he and his colleagues point out that we typically find out about a system indirectly, that is, we look at the system's effect on some small part of its environment. For example, when we look at a tree, in effect we measure the effect of the leaves and branches on the visible sunlight that is bouncing off them.

But it was not obvious that this kind of indirect measurement would reveal the robust, decoherence-resistant pointer states. If it does not, the robustness of these states won't help you to construct an objective reality.

Now, Zurek and colleagues have proved a mathematical theorem that shows the pointer states do actually coincide with the states probed by indirect measurements of a system's environment. "The environment is modified so that it contains an imprint of the pointer state," he says.

All together now

Yet this process alone, which the researchers call 'environment-induced superselection' or einselection[2], isn't enough to guarantee an objective reality. It is not sufficient for a pointer state merely to make its imprint on the environment: there must be many such imprints, so that many different observers can see the same thing.

Happily, this tends to happen automatically, because each individual's observation is based on only a tiny part of the environmental imprint. For example, we're never in danger of 'using up' all the photons bouncing off a tree, no matter how many people we assemble to look at it.

This multiplicity of imprints of the pointer states happens precisely because those states are robust: making one imprint does not preclude making another. This is a Darwin-like selection process. "One might say that pointer states are most 'fit'," says Zurek. "They survive monitoring by the environment to leave 'descendants' that inherit their properties."

"Our work shows that the environment is not just finding out the state of the system and keeping it to itself", he adds. "Rather, it is advertising it throughout the environment, so that many observers can find it out simultaneously and independently."

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References

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