How backwards-in-time effects could explain quantum weirdness

Since the earliest days of quantum theory, physicists have struggled to reconcile the apparently nonlocal, faster-than-light interactions demanded by quantum mechanics with the strict laws of relativity. Dr Rod Sutherland at the University of Sydney, Australia, believes that the answer to this problem lies with ‘retrocausality’ – a concept which would allow quantum measurements to influence events in their past. Through a detailed new mathematical description, Sutherland aims to bring retrocausality into the mainstream, potentially paving the way for solutions to some of the most long-standing mysteries in physics.

The phenomenon of quantum entanglement occurs at subatomic scale. Atomic and subatomic particles behave very differently from the macroscopic materials we interact with every day. The states of its entangled partners, no matter how far apart they are separated.

Many physicists have baulked at this idea – including Einstein, who argued that according to his own theory of relativity, such ‘nonlocal’ interactions, which would require the influences from past events to travel faster than the speed of light, should be impossible.

These concerns were laid out in a famous thought experiment by John Stewart Bell in the 1960s. Bell examined whether the quantum predictions for pairs of entangled particles could be explained by some underlying ‘local hidden variables’: as-yet-undetectable properties of quantum particles which would create the illusion of communication between the particles while actually leaving them independent.

“His investigations resulted in Bell’s theorem, which apparently indicates that any such hidden picture would indeed need to be nonlocal,” Sutherland says. “This would require connections to persist between entities which have become widely separated in space.”

Beginning in the 1970s, physicists began to devise groundbreaking new ways to bring Bell’s thought experiment into reality. Since then, increasingly advanced variations of the experiment have shown time and again that the results predicted by quantum mechanics and assumed in Bell’s theorem really do occur in nature – apparently in direct contradiction with relativity.

Today, it remains unclear whether these observations really offer a final description of reality, or whether we might evade Bell’s theorem by identifying a natural, but invalid assumption which has been made in its derivation and thereby restore locality. For now, this has created a roadblock in quantum theory, and the debate over how we should interpret this outcome appears to have no end in sight.

INTRODUCING RETROCAUSALITY

Through his research, Sutherland advocates for a theory which he believes could finally bring an end to this deadlock. He argues that to avoid the need for the sort of faster-than-light influences implied by Bell’s theorem, we need to make a clean break with one of the most deep-rooted assumptions in physics: that an event can only be caused by events which occur in its past.

As Sutherland describes, “it has become clear to a number of people that the conclusions of John Bell’s famous proof can be avoided by easing the assumption that we can only exert an influence forward in time.”

To justify this theory of ‘retrocausality’, Sutherland draws on Heisenberg’s uncertainty principle. The principle states that we can never know both the position and momentum of a quantum particle simultaneously with perfect accuracy. This means that if we improve our measurements of one quantity, the accuracy of the other will suffer.

Following on from this law, Sutherland points out that the future values of some quantities in physics can never be pinned down precisely, and therefore can’t be predicted based on the results of previous measurements. As a result, this leaves open the possibility that an experiment’s choice for the next measurement to be performed could affect earlier values which were left unknown by the previous measurement.

This logic is reinforced by a second familiar aspect of quantum mechanics: that measurements not only provide information about a particle’s quantum state, but also exert an influence which can change that state. In keeping with this fact, the idea is that the situation is symmetric in time and the observers’
Behind the Research

Dr Rod Sutherland

Research Objectives

Dr Rod Sutherland has developed a model of retrocausality, which might pave the way for solving long-standing mysteries in physics.

Detail

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Bio
Rod Sutherland gained his PhD from the University of New South Wales, Sydney, Australia, and then worked as a senior lecturer in physics at Western Sydney University. Having retired from lecturing duties, Sutherland is now an Honorary Research Associate at the University of Sydney and enjoys life as an enthusiastic researcher and keen tennis player.

References

Sutherland, R.I., (2022) Probabilities and certainties within a causally symmetric model. Foundations of Physics, 52(4), 1–17. doi.org/10.1007/s10701-022-00573-x


Personal Response

What inspired you to conduct this research?

“In my undergraduate days, it bothered me that the lecturers would gloss over the question of whether the physical reality described by quantum mechanics actually consisted of particles or waves or something else. They just tried to give the impression that everything was all right, but I wasn’t convinced. Like many others, I was prompted to explore the question more deeply for myself.”

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In addition, Sutherland’s model of retrocausality enables him to provide a more detailed description of systems containing arbitrary numbers of entangled quantum particles. In existing

conceptions of quantum mechanics, this situation demands a complex, somewhat abstract description in a higher dimensional space. ‘The standard quantum mechanical description of N interacting particles occurs in a mathematical “configuration space” of 3N dimensions,’ Sutherland explains. ‘In contrast, the retrocausal picture of reality lies entirely in the usual physical space of three dimensions.’

Solving Theoretical Conundrums

Far from clashing with the core principles of quantum mechanics, Sutherland believes that his model of retrocausality goes hand in hand with them. In his description, entangled quantum particles reside in our everyday space and obey Einstein’s laws of relativity – despite

an acceptance of retrocausality could pave the way for new breakthroughs in our understanding of our universe.

By allowing for backwards-in-time effects in their theories, Sutherland hopes that researchers may finally be better equipped to answer some of the most pressing questions in physics. ‘In general, introducing the possibility of retrocausal effects also allows other problems in physics to be approached in a fresh way,’ he continues. ‘For example, it allows the possibility of a simpler approach to a theory of quantum gravity.’

This particular field of research aims to describe gravity using the language of quantum mechanics – despite the fact that these two parts of physics appear to abide by entirely different laws according to our current understanding. Einstein’s explanation of gravity, via his general theory of relativity, deals in definite, well-defined quantities. In contrast, quantum mechanics only predicts probabilities rather than certainties and leaves the corresponding picture of physical reality ‘fuzzy’ rather than definite. This in turn seems to require the spacetime in Einstein’s picture, which behaves curved and distorted by gravity, to become indefinite as well.

With retrocausality included, however, the picture becomes quite definite again once the future influences are taken into account. ‘This allows the possibility of a simpler description of quantum gravity,’ says Sutherland. ‘The fuzziness only returns once we are forced to take an average over the unknown future values which cannot be accessed in advance.’

An acceptance of retrocausality could pave the way for new breakthroughs in understanding of some of the more mysterious phenomena in the universe – including black holes and neutron stars, where quantum mechanics and general relativity cannot both continue to apply in their present forms.

If his mathematical description becomes more broadly accepted among the wider physics community, Sutherland hopes that roadblocks which have persisted since the birth of quantum theory could be broken down, ultimately leading to a greater understanding of how our universe behaves on a fundamental level.

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choice of measurement interaction not only affects subsequent events, but also those in the past.

Compatibilism with Quantum Theory

The idea that apparently nonlocal interactions could be explained by backwards-in-time effects has been suggested by others in the past. Until now, however, most discussions have not provided a detailed mathematical description of retrocausality. In his research, Sutherland has developed such a description for the first time as well as showing how to incorporate it into other parts of physics.

In doing so, his theory successfully reproduces key predictions from quantum mechanics while allowing entangled quantum particles to be treated as independent in the sense of no faster-than-light influences occurring between them.

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