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The Dilemma of Randomness and Super-Determinism

In Physical Randomness Extractors, Kai-Min Chung, Yaoyun Shi, and Xiaodi Wu now strengthen earlier results of Rodrigo Gallego, Lluis Masanes, Gonzalo de la Torre, Chirag Dhara, Leandro Aolita, Antonio Acin in Full randomness from arbitrarily deterministic events.

These papers provide a simpler, clearer, and more difficult to evade formulation of a fundamental dilemma in physics. This dilemma has very important philosophical implications.

The dilemma can be stated concisely as follows. If quantum mechanics provides a true description of Nature, and there is currently absolutely no evidence whatsoever that it does not and overwhelming evidence that it does, then either (a) all of Nature is completely determined, including exactly what setups physicists choose for their experiments and observations (this view is called "super-determinism"), or (b) there is a fundamental, irreducible, physical source of genuine randomness and unpredictability in Nature.

To quote Gallego et al.:

From a more fundamental perspective, our results imply that there exist experiments whose outcomes are fully unpredictable. The only two assumptions for this conclusion are the existence of events with an arbitrarily small but non-zero amount of randomness and the validity of the no-signalling principle. Dropping the former implies accepting a super-deterministic view where no randomness exists, so that we experience a fully pre-determined reality. This possibility is uninteresting from a scientific perspective, and even uncomfortable from a philosophical one. Dropping the latter, in turn, implies abandoning a local causal structure for events in space-time. However, this is one of the most fundamental notions of special relativity, and without which even the very meaning of randomness or predictability would be unclear, as these concepts implicitly rely on the cause-effect principle.

The reason these results are important is they prove that, if there is any randomness at all in Nature, then there is genuine, irreducible, physical randomness at the most basic level of Nature that can be captured, amplified, and used for engineering purposes. It is all, or nothing. Nature is completely determined, or it features real, irreducible, physical unpredictability.

These results are related to the Bell inequalities, the Kochen-Specker theorem, the Strong Free Will Theorem of Conway and Kochen, and so on. For what appears to be an informed discussion of the Free Will Theorem, see this. To me, the randomness dilemma seems to be not only an easier way, but as far as I can tell a stronger way, to get at the weirdness of quantum mechanics and, probably, of Nature.

From these results, I draw two philosophical inferences.

The first, and perhaps most important, inference is that science may never provide us with any way of empirically or mathematically deciding between super-determinism and irreducible randomness. This may be a permanent, empirically undecidable dilemma. Any choice of one horn over another may come down to philosophical arguments or even personal intuition.

The second inference is that the philosophical fuzziness of the dilemma has been sharply reduced. This is huge progress! With respect to determinism, there is actually only super-determinism. With respect to indeterminism, there is actually only the physically irreducible unpredictability of certain quantum processes.

There do not appear to be any other viable philosophical conceptions of determinism or indeterminism at this time.

The reason that Gallego et al. think that indeterminism is philosophically “uncomfortable” is the same as that discussed by Conway and Kochen (whom Gallego et al. probably had in mind): scientists have always sought universality in the laws of Nature, and part of this universality involves assuming that experimenters are, in fact, free to set up experiments any way they please, yet the laws of Nature will still apply.

So, super-determinism seems to be somewhat in tension with some very basic principles, or philosophical presuppositions, of the scientific worldview.

Or, perhaps even more intriguingly, the dilemma may be pointing us to some inconsistency or incompleteness in the philosophical presuppositions that underlie the scientific worldview. After all, both determinism and settings independence have been assumed by most scientists to be aspects of Nature.

It is worth noting that Jason Gallicchio, Andrew S. Friedman, and David I. Kaiser have proposed experiments to close the last remaining loophole in experimental tests of the Bell inequalities, the “settings independence” loophole, by using photons from two quasars, on opposite sides of the universe, to select detector settings. These quasars could not have been in each others’ past light cones since the big bang, which as far as we are concerned is the beginning of time.

If such an experiment were to be performed, closing all other loopholes, several outcomes are possible.

Most likely the Bell inequalities would be violated for every combination of redshifts and angular separations of cosmic sources, regardless of whether the sources’ past light cones shared any overlap since the hot big bang. Such results would be in keeping with the predictions of quantum mechanics. In that case, the experiment would have succeeded in closing what is arguably the most crucial outstanding loophole in tests of Bell’s inequality. All local hidden-variable theories would be constrained as much as is physically possible in our universe, except perhaps for super-deterministic cosmic conspiracies, which themselves may not be falsifiable The inference that Bell tests imply that the universe is truly non-local would then be on as firm a ground as possible.

The success of this experiment would not absolutely rule out super-determinism. But it would make super-determinism extremely hard to think.

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