

Quantum mechanics: Why isn't nature more non-local?

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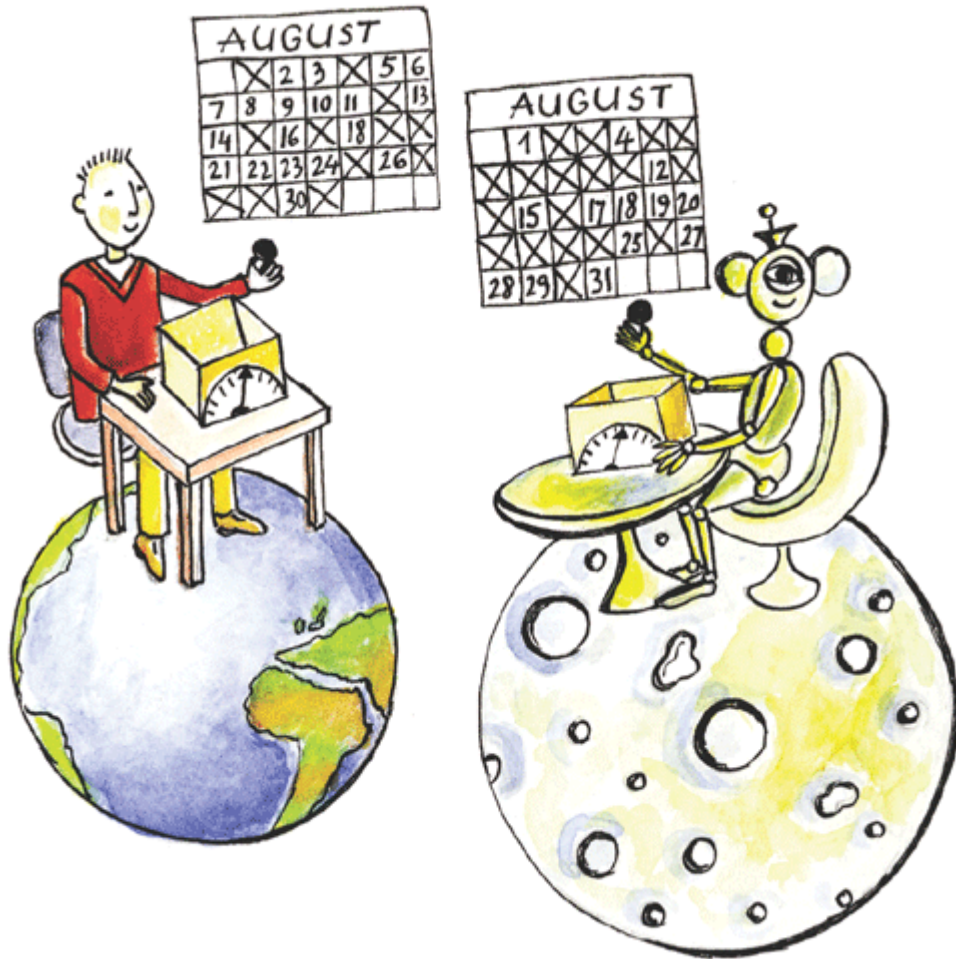
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Many predictions and consequences of quantum mechanics defy intuition. New insights into the limits of communication between spatially separated parties could bring us closer to grasping the nature of the quantum world.

Microscopic particles — molecules, atoms, subatomic particles and so on — behave very strangely and very differently from ordinary objects like footballs, pebbles and chairs. We have a very good theory to explain their behaviour: quantum mechanics. But all is not good. More than seven decades after the discovery of quantum mechanics, it is fair to say that we lack an intuitive and deep understanding of it — witness the many puzzles and surprises that are discovered routinely. It is still an open question why quantum behaviour is what it is. But Brassard *et al.*, reporting in *Physical Review Letters*¹, take a significant step in unveiling the mystery.

One of the strangest things microscopic particles can do is to yield non-local correlations. Suppose two experimentalists, Alice and Bob, are situated in two remote labs, say on two different planets ([Fig. 1](#)), and perform measurements on particles that come from a common source and are in an 'entangled' state. Even if the measurements are performed simultaneously, so that no information from Alice can reach Bob before his measurement is finished, and *vice versa*, the results of their measurements can be correlated. This is no surprise — after all, the particles came from the same source. What is astonishing, however, is that they are correlated in such a way that if we try to simulate the correlations with macroscopic systems, a consistent result can only be obtained if Alice and Bob's systems communicate with each other during the measurements. However, due to the timing of the experiment, this communication would have to be faster than light.

[Figure 1: Keep communication simple.](#)



How much information does Earth-bound Bob have to send to extra-terrestrial Alice in order to fix a date?

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That non-local correlations can exist at all and do not lead immediately to a conflict with Einstein's relativity is possible only due to the fact that the results of measurements on microscopic particles are probabilistic. Non-locality is thus related to the most fundamental aspect of quantum mechanics, non-determinism.

This led Yakir Aharonov (personal communication) and Shimony² independently to suggest that non-locality might be the basic element of quantum mechanics, the reason why quantum mechanics is what it is. Following their suggestion, Popescu and Rohrlich³ asked whether quantum mechanics is the only theory that can combine relativity, that is, finite speed for signal propagation, with non-locality. Surprisingly, they found that the range of non-local correlations that are compatible with non-superluminal signalling is larger than the ones that can be generated by quantum mechanics. But are there such 'super-quantum' correlations in nature, they asked, and, if not, why not? And what could be a new axiom to uniquely determine quantum mechanics, in addition to obeying relativity and the existence of non-locality?

Let us return to Alice and Bob. One day Alice and Bob decide to meet each other for the first time. But they are so busy that finding even one good day when both are free is quite daunting. To make a boring task more fun, they decide to play a little game. Rather than trying to find a good day directly, they first want to know whether the number of good days available this year is even or odd. Alice sending her entire schedule to Bob would do the job, but this involves a lot of communication. And Bob learns more than what he wanted; he finds out not only if the total number of good days is even or odd, but also exactly which the good days are. Could they do better, with less communication? In the end, all Alice and Bob want to find out is a single bit of information — whether the total number N is 'even' or 'odd' — so why send N bits, a 'free' or 'busy' day for each of the N days of the year? This is an example of a 'communication complexity' problem.

Unfortunately for Alice and Bob, computer scientists have proved that sending the entire calendar is a necessity. There is no better way. But what if Alice and Bob share pairs of entangled quantum particles? After all, the particles have non-local correlations — perhaps Alice and Bob could use them. This isn't as crazy as it seems at first sight: Cleve and Buhrman⁴ found that non-local correlations can indeed help in some communication problems. However, it has also been shown by Cleve *et al.*⁵ that quantum mechanical correlations cannot help Alice and Bob with their 'even versus odd' problem.

That quantum mechanics cannot help is unfortunate indeed, because Alice and Bob's calendar problem is not just an idle game. In fact, every single communication complexity problem in which Alice and Bob want to learn just one bit of information can be reduced to this particular problem (technically called the 'inner product'). Thus, if the inner product problem could be solved by communicating a single bit, than any other problem can be solved by a single bit too.

A breakthrough came when van Dam^{6,7} showed that particles that could yield a particular type of super-quantum non-local correlations (so-called 'maximally non-local' correlations) can help solve the inner product problem with a single bit of communication. These maximally non-local correlations would then render all communication complexity problems trivial. A world with such correlations would be very strange indeed: all communication complexity tasks could be performed by sending one bit.

The maximal non-local correlation, however, is a very particular one. And here, finally, come Brassard and his colleagues¹. They suggest, and make significant steps towards proving, that not only this maximal correlation, but all correlations stronger than those provided by quantum mechanics may render communication complexity trivial.

So, according to Brassard *et al.* the reason why quantum mechanics is not more non-local than it is, is because otherwise it is very likely that all communication complexity would be trivial. But why wouldn't nature allow all communication to be trivial? Or does it? The search is still on.

References

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