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The Big Bell Test

Global physics experiment challenges Einstein with the help of 100,000 volunteers

Simultaneous experiments on five continents challenge Einstein's principle of local realism. Participants contributed to the experiment generating more than 90 million bits, unpredictably choosing among measurements to escape a problem known as the "freedom-of-choice loophole". The study has been published in *Nature (10 May 2018)*.

On November 30th, 2016, more than 100,000 people around the world contributed to a suite of first-of-a-kind quantum physics experiments known as **The Big Bell Test**. Using smartphones and other internet-connected devices, participants contributed unpredictable bits, which determined how entangled atoms, photons, and superconducting devices were measured in twelve laboratories around the world. Scientists used the human input to close a stubborn loophole in tests of Einstein's principle of **local realism**. The results have now been analysed, and are reported in this week's *Nature*.

In a Bell test (named for the physicist John Stewart Bell), pairs of entangled particles such as photons are generated and sent to different locations, where particle properties such as the photons' colours or time of arrival are measured. If the measurement results tend to agree, regardless of which properties we choose to measure, it implies something very surprising: either the measurement of one particle instantly affects the other particle (despite being far away), or even stranger, the properties never really existed, but rather were created by the measurement itself. Either possibility contradicts **local realism**, Einstein's worldview of a universe independent of our observations, in which no influence can travel faster than light.

The Big Bell Test asked human volunteers, known as ***Bellsters***, to choose the measurements, in order to close the so-called "freedom-of-choice loophole" – the possibility that the particles themselves influence the choice of measurement. Such influence, if it existed, would invalidate the test; it would be like allowing students to write their own exam questions. This loophole cannot be closed by choosing with dice or random number generators, because there is always the possibility that these physical systems are coordinated with the entangled particles. Human choices introduce the element of free will, by which people can choose independently of whatever the particles might be doing.

Led by ICFO-The Institute of Photonic Sciences, in Barcelona, the BIG Bell Test recruited participants worldwide to contribute unpredictable sequences of zeros and ones (bits) through an online video game. The bits were routed to state-of-the-art experiments in Brisbane, Shanghai, Vienna, Rome, Munich, Zurich, Nice, Barcelona, Buenos Aires, Concepción Chile and Boulder Colorado, where they were used to set the angles of polarizers and other laboratory elements to determine how entangled particles were measured.

Participants contributed with more than 90 million bits, making possible a strong test of local realism. The obtained results strongly disagree with

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Einstein's worldview, close the freedom-of-choice loophole for the first time, and demonstrate several new methods in the study of entanglement and local realism.

The MPQ-LMU Experiment

As a part of this global effort, the MPQ contribution was two-fold: First, in the design of the game through which participants around the globe input their bits, through a prediction engine (also called "oracle" in the game) that made participants aware of the predictability of human-generated randomness. "I remember having a tough time beating the oracle at the last level of the game," says Jordi Tura, who designed the prediction engine of the game.

Second, the MPQ-LMU team led by Wenjamin Rosenfeld and Harald Weinfurter used the contributed bits for testing Bell's inequality on a single atom trapped in one laboratory and a single photon which was entangled with the atom and then guided to another laboratory 400 m away. To make this game even more exciting, the scientists additionally used so-called quantum random number generators (QRNGs), the best nowadays known sources of randomness, placed in both laboratories. Thereby the human contributors could additionally decide for each measurement, whether a human or a QRNG would select the measurement settings, allowing to compare them.

In the MPQ-LMU test, both datasets, the human-decided and the QRNG-decided, show the same level of violation of Bell's inequality. While this does not necessarily mean that humans can produce randomness of the same quality as specialized devices can do, it introduces a different kind of making unpredictable choices in quantum experiments. "This day was a lot of fun. There was great feedback on Twitter and many of our friends and even parents have played the game," says Kai Redeker (LMU) who was conducting the experiment. "Using human decisions for such tests is a novel and exciting way for addressing the freedom-of-choice loophole," emphasizes Wenjamin Rosenfeld. "Still, there is a lot to be done for closing all experimentally addressable loopholes in such experiments," adds Harald Weinfurter, "but we are on a good way."

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The Big Bell Test Collaboration

Challenging local realism with human choices

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