Contributors

Lilit Adamyan and Iren Okminyan.

Project description and questions

In this activity, you will read an article, submit a written response. Please read the directions below carefully and complete the assignment in full.

There are two alternatives to answer the questions. You can either read the paper *Challenging Local Realism with Human Choices* or visit the website thebigbelltest.org. You will find the same information in both alternatives. However, we encourage you to read the paper and check the website, or explore all the sections of the website and scan the paper. We also encourage you to play the Big Bell Test Game.

Prepare a response for each of the following prompts below (300-500 words overall).

1. There is a whole scientific community interested in providing an indisputable proof that nature violates Bell's inequality. Explain why the Big Bell Test assures that they closed all the loopholes and what does it imply for our understanding of the universe.
2. Gamification is a powerful tool that can be used in several contexts, such as marketing and generation of products. Explain how The Big Bell Test experiment utilized gamification for generating random numbers and imagine and discuss other possible applications of gamification in quantum computing.
3. Choose two of the thirteen nodes of the Big Bell Test experiment and compare their physical system, degree of freedom measured, rate of bits consumed and total number of bits, how where the bits used, how long the experiment took, and the distance between Alice and Bob.

Question 1

To answer the question, let us first define the Bell Test.

The goal of Bell Test is to get results from experiments (randomized trials) and compare them to the concept of locality. The latter includes the idea that the properties of the physical world are independent of our observation of them and no signal travels faster than light.

In other words, its goal is to test whether or not the real world satisfies local realism, which can be explained by the presence of some additional local variables (called "hidden" because they are not a feature of quantum theory) to explain the behavior of particles like photons and electrons.

The issues arising in experimental implementations, which are against the assumptions of Bell's theorem called **loopholes**. In order to provide a proof that nature violates Bell's Test, all loopholes should be closed, as the results can be biased by the loopholes and may not lead to accurate conclusions. Therefore, it is very important to assure that all loopholes are closed during the experiments. To see why this is a big problem, we will demonstrate some loophole examples and their possible solutions.

Detection-efficiency loophole, for instance, describes the possibility that the observed statistics are inaccurate because of selection bias. It is closed using high efficiency detection and statistical methods that analyse all trials.

The locality loophole describes the possibility that a choice at one station can influence another station's measurement result. BBT tightens locality loopholes using many independent experiments.

The freedom-of-choice loophole describes the possibility that particle properties can be affected by the setting choices being influenced by 'hidden variables' . In other words, if Alice and Bob have genuine 'freedom' in deciding how to measure entangled particles, then the particles must also have 'freedom' in deciding how to respond to the measurements. In BBT human capacity for free choice closes the freedom of choice loophole.

Bell himself argued that human choices could be considered 'free variables' in a Bell test. BIG Bell Test(BBT) implements Bell's idea, using modern crowd-sourcing, networking, and gamification techniques. Here Alice and Bob of Aaronson's formulation are real people. Assuming no faster-than-light communication, such experiments can prove the conditional relation: if human will is free, there are physical events (the measurement outcomes in the Bell tests) that are intrinsically random, i.e., impossible to predict.

As BBT assures that all loopholes are closed, the results of the test contradict local realism, and implies that there exists a signal that travels faster than light (and forces us to think that the properties of the physical world are dependent on our observation of them). This changes our world perception revolutionary and even makes some scientists to assume that two entangled particles change information over black holes.

Question 2

Now let's discuss how the Big Bell Test works. About 100,000 human participants are recruited to play an online video game . The participants generated 97,347,490 binary choices, which were directed via a scalable web platform to 12 laboratories on five continents, where 13 experiments tested local realism using photons, single atoms , atomic ensembles, and superconducting devices. To choose each measurement setting different human-generated data was used : over a 12-hour period on 30 November 2016, participants provided a sustained data flow of over 1,000 bits per second to the experiments.

The challenge of the game is to produce random bits, avoiding being predicted by the Oracle, where the Oracle is a machine-learning algorithm that predicts player behaviour based on patterns in past input. Most player time was spent in a rapid ‘speed game’, in which the participant moves along a road by hitting 0s and 1s. This part of the game requires rapid bit generation in order to complete the level in time.

The player is tasked with entering a given number of unpredictable bits within a limited time. A machine learning algorithm (MLA) attempts to predict each input bit, modelling the user’s input as a Markov process and updating the model parameters using reinforcement learning. Scoring and level completion reflect the degree to which the MLA predicts the player’s input, motivating

players to consider their own predictability and take conscious steps to reduce it. All input is passed to the experiments. Players input showed unsurprising deviations from ideal randomness.

The same bits were sent to many experiments, which used them for individual settings. Most experiments observed statistically strong violations of their respective inequalities, justifying rejection of local realism in a multitude of systems and scenarios.

As a gamification application we think about a game with a lot of video materials about quantum computing, where a player should complete tasks of increasing difficulty. Like our QC homeworkes. Each next task is opened for completion after getting predefined scores from previous tasks. And scientists who want to implement their work can upload their research papers and organize competition among the players and prize them. Players with equal scores can organize a team and work together on projects. This platform will involve and encourage a lot of students interested in quantum computing.

Question 3

We chose the following experiments to compare:

III. Bell tests with imperfectly random human input,

VII. Violation of a Bell inequality using superconducting qubits.

Let us firstly list the characteristics and only then comment on them:

	III	VII
physical system	*entangled photon pairs*	*entangled superconducting qubits*
degree of freedom measured	*γ polarization*	*transmon qubit*
rate of bits consumed	*1 kbps*	*3 kbps*
total number of bits	*80 Mb*	*16.34million numbers*
how the bits were used	*(discussed above)*	*(discussed above)*
experiment duration	*1.5h*	*48h*
Alice and Bob distance	*87 ± 2 m and 88 ± 2 m*	*1 mm*

- Physical states

In chosen experiments systems differ by the type of the qubits. In III we have entangled photons, while in VII - entangled superconductive qubits.

- Degree of freedom measured

In III, one of the most popular degrees of measurement is used - polarization. We followed the cited article [1801.05723] Entanglement between a photonic time-bin qubit and a collective atomic spin excitation , and found out about most used ones. However, in that article we did not find the transom qubit. Then we followed another cited source and learned that transom qubits are new superconducting qubits with their specifications ([0803.4490] Controlling the spontaneous emission of a superconducting transmon qubit).

- Rate of bits consumed

We can note that in VII, the bit rate was 3 times higher.

- Total number of bits

In the VII experiment 80Mb of data (human-generated numbers) were used. In the III, according to the article, 16.34 million numbers were used which is ~ 2Mb (if by saying numbers they meant bits).

- How the bits were used

III. To make it short, after the photons are generated, they get collected. After they are detected to be sure, Alice's and Bob's detection stations will not affect each other. After, numbers/bits are used: the Pockels cells apply a zero or a half-wave voltage based on the value of random numbers, thus setting the basis for Alice and Bob. Next, photons are detected.

VII. In this experiment, the pairs of bits were used to perform trials. They were used to execute one of the 4 quantum circuits, which is then followed by measurement.

- Experiment duration

The III experiment lasted 1.5 hours, while the VII lasted 48 hours, although the input bits were far less. In the latter, out of the input, 8.17 million individual Bell measurements were performed, with 7.69 million had successful state initialization and calibration.

- Distance between Alice and Bob

In case of VII, Alice and Bobwere separated by almost 180m, while in III - just 1mm.

To sum up, the following experiments differed from each other with every characteristic, listed in the paper. They both used human-generated bits but for different purposes, different qubits, systems, distances etc.

Links

https://arxiv.org/abs/1805.04431

https://thebigbelltest.org/