Quantum Computing Final Project Task 3

Written by Erik Davtyan
Proofread by Varazdat Stepanyan

Question 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.

Prominent scientists like Einstein believed that QM can't be as weird as our current theory suggests, and that the universe should be governed by realism and localism. To explain how the QM experiments "prove" otherwise, they suggested that there might be hidden variables at play - quantum particles exchanging information when being entangled, and then using that information to know what state to collapse to when measured. However, Bell's inequality, which is a logical upper bound on the statistical correlation of 2 classic local and real objects, has been violated a lot of times in QM experiments. Those experiments had "loopholes", which would theoretically allow for realism and locality to still exist. For example, if a machine that generates random numbers (0 or 1) could in some way be affected by the experiment itself (FoCL - Freedom of Choice Loophole), then it would be impossible to disprove the hidden variables theory based on an experiment made with a random number generator. However, if instead of a machine, we used humans to generate random numbers, that loophole would be as close to being solved as possible. If we assume the universe is *superdeterministic*, then we can't go forward any further with our proofs, as all results are predetermined and won't prove anything. If we assume that human thought is *not* free, then from our perspective that's not much different from a superdeterministic universe. So we are left with the best option to close that loophole - assuming that human choice is free.

During Bell's times there was no internet, so it was impossible to get enough humanly generated data for it to have statistical significance. But with current communication technologies and gamification techniques, the Big Bell Test was able to bring together 100.000 people, each of whom generated a lot of numbers between 1 and 0. While those numbers weren't truly random and had patterns in them, from the point of view of just closing the loophole, they were good enough. Thus, the FoCL loophole was closed. Other loopholes like space-like separation were also closed by having many different experiments run at the same time with the same bits all over the world, and by having space-like separated measurements in space-like separation (for example, in experiment 3, photons shooting out in different directions and being measured 87±2 m and 88±2 m, thereby not having enough time to affect the measurement from one end to the other).

Question 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.

As I explained in my answer to the first question, gamification was a crucial part of getting tens of thousands of people to tune in and input random numbers into a system. This goal would be completely unattainable without gamification, as very few people would tune in and start inputting 0s and 1s into a text box. Also, giving people a goal of inputting as "unpredictable" as possible, created a real challenge and made random number generation way more fun. To battle the numbers generated by bots, the experimenters had scripts to detect them. Upon detection they did not block them though - they simply stopped sending the data to the server, to avoid the bots getting replaced by more clever and hard-to-spot alternatives.

Reading this experiment I thought about gaming in general and how many random numbers are being inputted in a game. If we consider a racing game for example, there are a lot of "micro-actions" that take place. The user constantly slightly changes the direction of the car, or the camera angle. Getting many of those micro-actions together (instead of just taking the car direction angles, as those are very predictable based on the road) can create a huge stream of randomly generated numbers, that can then be converted to binary and used in experiments where human-generated random numbers are necessary.

Currently, other than those kinds of experiments, gamification can be used for educational purposes. Similar to how there are programming/logic games for children (for example - Swift Playgrounds https://www.apple.com/swift/playgrounds/), there can be gamified and visualised quantum experiments as well. For example, it can start with easier levels of guessing the probability of the measurement outcome of a quantum system evolution, or a puzzle-like creation of quantum algorithms using gates. QM is so inherently counterintuitive and fascinating, that visualisations of it are already super interesting. I can only imagine how interesting the gamification can be.

Another example of gamification use in QM is described in the paper "Exploring the quantum speed limit with computer games" in the science journal Nature. An easy explanation of the gamification method is descibed in this Medium article - https://medium.com/scienceathome/how-to-do-quantum-physics-research-by-playing-games-d7395cadc393. The game saves the creative ways that players move around the quantum atoms, then the researchers retrieve those paths and start examining them further to see if they can be used in a quantum computer.

So, using the freedom of choice and the creativity of people, it is possible to drive forward QM, and by using the results we get and explaining them in a visual and gamified format, it is possible to get more people interested in this fascinating field.

Question 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.

As I mentioned in the answer to the Question 1 - the detectors in the experiment #3 were space-like separated. The other experiment with the same feature was #13, so let's discuss those 2.

#3: The experiment used entangled photons. The measurement devices of Alice and Bob were both around 90 meter distant from the entangled pair generating laser - therefore making sure that the measurement in Alice's detection station will not affect that in Bob's detection station, and vice versa. The degree of freedom $l = minxy \lambda P(xy|\lambda)$ was 0.10 ± 0.05. More than 80 MB of human generated random numbers was used during the 2 days that the experiment ran. The maximum human-generated bitrate was 1kbps. The generated random numbers were used to choose the measurement basis.

#13: This experiment also used entangled photons, and the measurement stations were about 187 meters apart. It used 81,119,980 human-generated bits, and ran over the course of 7 minutes (about 200kbps). The decisions on how to set the Pockels cells for measurement are dictated by the bits supplied by the participants.