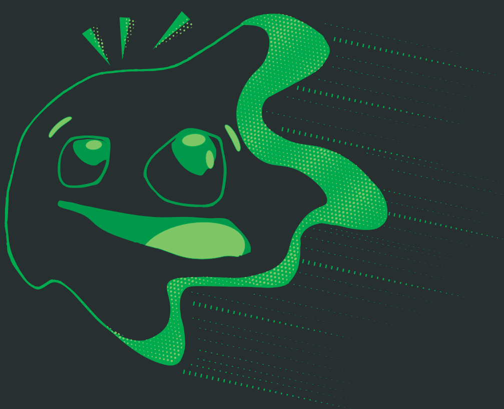

QUANTUM
GHOST HUNT

WELCOME TO QUANTUM GHOST HUNT

You are an eccentric ghost who likes to keep his true identity hidden from the public, and you have been living peacefully in a physics lab for several decades. For a long time you thought you were safe, until the physicists in the lab decided to investigate the possibility of transmitting entangled photons over the air. Your very own existence is now in jeopardy as entangled photons can magically reveal cloaked objects!

Your task is to escape several lab situations, while avoiding collision with some randomly bouncing photons (red pixels). Like every quantum mechanical process, entanglement generation is probabilistic in nature, which is to say our physicists sometimes succeed in generating entangled photon pairs, while other times they just fail. This will be apparent when the ghost faces different lab situations. To avoid being snared by entangled photons, our ghost can use the knowledge it gathered secretly while living in disguise. A quantum measurement would devour the position uncertainty of the photons and localize them. Hence, if our ghost managed to measure the position of the bouncing photons, they would freeze and the ghost can avoid an imminent collision. This can be achieved by using a green button that the player may find inside the lab. The player can move the ghost using the arrow keys, while the X-key terminates the game.



THE QUANTUM CONCEPTS OF THE GAME

QUBITS

Qubits are the quantum mechanical analogues of classical bits of information. They possess this unique feature of occupying a coherent superposition state. One way to realize qubits is to encode our information into single photon states, specifically, the polarization states of single photons.

SUPERPOSITION

A photon moving in the air has two attributes, a direction of motion and a direction of oscillation(photons wiggle up and down as they move). The direction of oscillation is perpendicular to that of motion. These oscillations are also known as photon polarization direction. As can be seen in Fig.1 polarization is a versatile property, it can be any rotated vector in the plane perpendicular to the direction of motion. Usually light sources generate photons at all possible polarization directions, hence by choosing the appropriate polarizer we can filter out unwanted states and have our preferred superposition state.

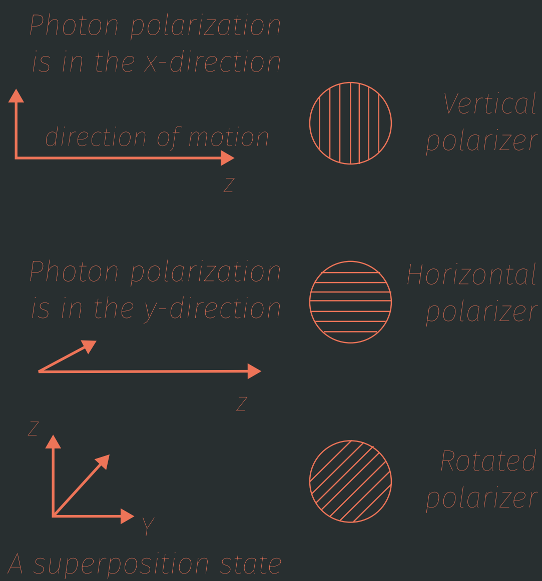


Fig. 1: Polarizers are devices that can be oriented to match the photon's polarization direction.

ENTANGLEMENT

Photons are bosons (a super fancy way of saying multiple photons can occupy the same state), so we can put two of them together in the same polarization state. Then we can use the same polarizer trick for single photons and create a two-photon superposition state. Imagine now that you possess two identical fair coins and you were asked to toss them, the outcome of your experiment can simply be any of the four possible states {H,H}, {H,T}, {T,H}, {T,T}. Each run of the experiment will certainly land on one of the four possible outcomes, furthermore, you can easily track the roundtrip path taken by each coin and predict exactly which state the two coins would eventually assume. Consequently, you can write down a definite joint state of the two coins.

Suppose now that for some reason you are stripped off the luxury of tracking the paths taken by the two coins, nonetheless you are equipped with a tiny piece of information that says there is a 50/50 chance that the final state of the two coins is either {H,H} or {T,T}. This means that our best state of knowledge of the two coins is probabilistic, moreover, we can see that the state of the first coin is in some sense overdetermined by the state of the second, and vice versa. In other words, whenever the first coin is heads, the second one is definitely a heads too, and similarly if the first one was tails. Similar situations usually arise quantum mechanically owing to the uncertainty principle. We usually start with an initial state and end up with some final state without knowing exactly which path was taken to reach this specific final state. In these situations the best we can do is to assign some probabilities to the possible paths. This means that our overall state of knowledge in such cases is a superposition of these possible states.

Phew! We are almost done, quantum entanglement is an uncertain state of knowledge that arises when a two-photon (coins) superposition state can't be factored into the product of two separate states (a definite joint state as in the first coin example), each representing a single photon (coin). We can think of this superposition state as two possible paths that can be taken by both photons. An entangled state is characterized by an inimitable type of correlation, that is, whenever we measure one of the two photons we learn immediately about the state of the other, even if they were dislocated earlier. It is not like the particles are secretly communicating or something, it is just that we encoded this correlation when we assigned the superposition state to them both.

THE GHOST HUNT

Our ghost faces two possible environments, one where it encounters a pair of entangled photons, while in the other it just faces single non-entangled ones. The entanglement is generated via a noisy quantum circuit that succeeds probabilistically. When the circuit successfully generates entangled photon pairs, we get two bouncing red pixels. On the other hand, when it fails, we just get a single bouncing one. The level with the entangled pixels is a bit harder, so we introduced an aiding tool (measurement device) to help the player get through the level. The measurement device simulates a projective measurement that can localize the pixels, and then it is really easy for the player to reach the exit door.