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Can We Hear the Sounds of Quantum Superpositions?*

Vlatko Vedral[1]
University of Oxford, Department of Physics
Centre for Quantum Technologies, National University of Singapore

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Abstract

In this article I explore the possibility of being able to hear the sound of a quantum superposition of two sounds. What would it mean and is it feasible to explore performing an experiment that would allow us to test this notion?

Keywords: quantum mechanics, superposition, sound, Schrödinger's cat

In an earlier exposition I argued that the idea that quantum mechanics applies to everything in the universe, even to us humans, can lead to some interesting conclusions (Vedral 2016; 2018a).[2] I will repeat part of the argument already presented in that article, simply for the sake of completeness, and then apply it to the question of hearing the sound of superpositions.

Consider David Deutsch's variant of the Schrödinger cat thought experiment (Deutsch 1986: 204–214) that builds on Eugene Wigner's ideas (Wigner 1961). Suppose that a very able experimental physicist, Alice, puts her friend Bob inside a room with a cat, a radioactive atom and cat poison that gets released if the atom decays. The point of having a human there is that we can communicate with him. As far as Alice is concerned, the atom enters into a state of being both decayed and not decayed, so that the cat is both dead and alive (this is where Schrödinger stops).

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1 vlatkovedral@gmail.com

2 A much less formal exposition of the same was presented in: Vedral 2011.

Bob, however, can directly observe the cat and sees it as one or the other. This is something we know from everyday experience: we never see dead and alive cats. To confirm this, Alice slips a piece of paper under the door asking Bob whether the cat is in a definite state. He answers, "Yes, I see a definite state of the cat".

At this point, mathematically speaking, the state of the system has changed from the initial state

$$|\Psi i\rangle = |\text{no-decay} > |\text{poison in the bottle} > |\text{cat alive} > |\text{Bob sees alive cat} > |\text{blank piece of paper} > \quad (1)$$

to the state (from Alice's global perspective)

$$\begin{aligned} |\Psi 1/2\rangle = \ & (|\text{decay} > |\text{poison released} > |\text{cat dead} > |\text{Bob sees dead cat} > + \\ & |\text{no-decay} > |\text{poison still in the bottle} > |\text{cat alive} > |\text{Bob sees alive cat} >) \otimes \\ & |\text{paper says: yes, I see a definite state of the cat} > \quad (2) \end{aligned}$$

I am assuming that, because Alice's laboratory is isolated, every transformation leading up to this state is unitary. This includes the decay, the poison release, the killing of the cat and Bob's observation - Alice has a perfect quantum coherent control of the experiment.

Note that Alice does not ask whether the cat is dead or alive because for her that would force the outcome or, as some physicists might say, "collapse the state" (this is exactly what happens in Wigner's version, where he communicates the state to a friend, who communicates to another friend and so on). She is content observing that Bob sees the cat either alive or dead and does not ask which it is. Because Alice avoided collapsing the state (in other words, she did not get entangled to her experiment), quantum theory holds that slipping the paper under the door was a reversible act. She can undo all the steps she took since each of them is just a unitary transformation. In other words, the paper itself also does not get entangled to the rest of the laboratory.

When Alice reverses the evolution, if the cat was dead, it would now be alive, the poison would be in the bottle, the particle would not have decayed and Bob would have no memory of ever seeing a dead cat. If the cat was alive, it would also come back to the same state (everything, in other words, comes back to the starting state where the atom has not decayed, the poison is in the bottle, the cat is alive and Bob sees alive cat and has no memory of the experiment he was subjected to).

And yet one trace remains: the piece of paper saying "yes, I see a definite state of the cat." Alice can undo Bob's observation in a way that does not also undo the writing on the paper. The paper remains as proof that Bob had observed the cat as definitely alive or dead half way through the experiment. (Note that I remain interpretation neutral. A Many Worlds[3] supporter would say that there are two copies of Bob,

3 [The Many-Worlds Interpretation (MWI) of quantum mechanics holds that there are many worlds which exist in parallel at the same space and time as our own. (Everett 1957; Deutch 1997).] *(Ed.)*

one that observes a dead cat and one that sees alive cat; a Copenhagen[4] or Quantum Bayesian[5] supporter could say that relative to one state of Bob the cat is dead, while, relative to the other, it is alive – either way, supporters of any interpretation ought to make the same predictions in this experiment).

However, before reversing the evolution (and after Alice receives a communication from Bob that he sees a definitive outcome), Alice can actually communicate with Bob again (the first communication being Alice's question whether Bob sees a definite state). This time she says to him (by slipping another piece of paper under the door): "From your reply I know you see a definite outcome, but I am now telling you that you are nevertheless in a superposed state of seeing both outcomes. Or, more precisely, there is a version of you (or of your consciousness or whatever) that sees the cat dead and one that sees the cat alive" (something similar was discussed in: Albert 1992). Even better, if Bob is himself a quantum physicist, Alice could just write down the equation describing the state of the laboratory on the same piece of paper. This equation would just be the same as Eq. (2).

Bob, if he trusts Alice (and why shouldn't he? – she is both a good friend and a good physicist), might be shocked. He might think "I see a definitive outcome, so how can I still be in a superposition?" This sounds like a double slit experiment in which each particle goes through only one slit at a time and yet we obtain an interference pattern at the end. This would be a clear violation of the Uncertainty Principle.[6]

The answer to this apparent conundrum is, of course, that Bob is not in a superposition. Rather, he is entangled to the cat and the poison and the decayed atom, exactly as above. And, being maximally entangled to something means not being in a superposition but in a mixed state. So Bob now knows he exists in two different "worlds" (or rather, each version knows about the other), yet each of the two versions of him feels as though they are safely operating within one world only. Note that even though this language sounds "manyworldish", what we are discussing is simply

4 [Today the Copenhagen interpretation is mostly regarded as synonymous with indeterminism, Bohr's correspondence principle, Born's statistical interpretation of the wave function, and Bohr's complementarity interpretation of certain atomic phenomena (Faye 2014).] *(Ed.)*

5 [Quantum Bayesianists maintain that rather than (either directly or indirectly) representing a physical system, a quantum state represents the epistemic state of the one who assigns it concerning that agent's possible future experiences. It does this by specifying the agent's coherent degree of belief (credence) in each of a variety of alternative experiences that may result from a specific act the agent may perform (Fuchs 2010).] *(Ed.)*

6 [One striking aspect of the difference between classical and quantum physics is that whereas classical mechanics presupposes that exact simultaneous values can be assigned to all physical quantities, quantum mechanics denies this possibility, the prime example being the position and momentum of a particle. According to quantum mechanics, the more precisely the position (momentum) of a particle is given, the less precisely can one say what its momentum (position) is. This is (a simplistic and preliminary formulation of) the quantum mechanical uncertainty principle for position and momentum (Hilgevoord and Uffink 2016).] *(Ed.)*

an experimental question. All interpretations of quantum physics will have to agree on the outcome, albeit they might be using different jargon to describe the situation.

In fact, Alice can perform measurements to confirm that Bob is in the entangled state in Eq. (2) without collapsing the state, and then send the experimental results to Bob to dispell any doubts (of course, Bob would have to trust her that she performed the relevant experiments and that the results he has received from her are indeed genuine).

Let's now apply this scenario to sound. The decaying atom, instead of triggering poison, now triggers a sound. If the atom has not decayed, it triggers another sound. In the above experiment, Bob now listens to it and splits into two. In one branch he hears one of the two sounds, while in the another one, he hears the other of the two sounds. All the above steps can then be repeated in direct analogy with the cat. But can this ever be tested?

I do not know the answer to this, but suppose that the two sounds are stored in our brain as two distinct quantum states. Admittedly, these states could be very complex, in the sense of involving many atoms and interactions between them.[7] If so, this could maybe give us a small window of opportunity to be able to do something like Alice. We could perhaps confirm that Bob hears a definitive sound and then possibly undo this observation (providing we understand enough about how it is stored), thereby demonstrating that Bob has heard two sounds at the same time (each of the two versions of him hearing the corresponding sound in two branches of the total quantum state). This seems closest to what quantum physics would allow us to do when it comes to hearing two sounds at the same time.

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7 I discuss related questions at greater length in: Vedral 2018b.

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Влатко Ведрал

Да ли је могуће чути квантну суперпозицију?

(Сажетак)

У овом чланку истражујем да ли је могуће чути квантну суперпозицију два звука. Шта би то, заправо, значило и да ли би имало смисла спровести експеримент који би нам омогућио да тестирамо ову замисао? Након описа једног могућег експеримента који се одвија у квантној лабораторији, а чији су протагонисти двоје квантних физичара, Алис и Боб, примењујем исти сценарио на звук. Можемо замислити да су два звука ускладиштена у нашем мозгу као два различита квантна стања. Ова стања могу бити веома сложена, у смислу да садрже велики број атома и могућих интеракција између њих. Можда бисмо могли да потврдимо да Боб заиста чује неки звук, а затим да вратимо уназад читав поступак, демонстрирајући том приликом да је Боб чуо два различита звука у исто време (свака од две верзије Боба чује одговарајући звук у два засебна огранка тоталног квантног стања). Овако се највише приближавамо ономе што квантна физика може да нам понуди по питању истовремене чујности два звука.

Кључне речи: квантна механика, суперпозиција, звук, Шредингерова мачка