Observing Schrödinger's Cat

by

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draft April 14, 2020

Abstract: Schrödinger's thought experiment dramatically presents the discontinuity between a superposition and a classic measurement result. This paper explains this discontinuity and provides a consistent understanding of all measurements, by applying metrology - the science of physical measurements.

Keywords: Schrödinger's Cat; measurement; measure; calibration; accuracy;

When observables are measured in quantum mechanics (e.g., up or down, one slit or two, wave or particle), the observable presents an uncorrelated superposition. In metrology the measurement of an observable presents a magnitude in units calibrated (i.e., correlated) to a reference.[1] Euler explains that every measurement is correlated to another.[2] Einstein identified that all motions are relative[3] (i.e., correlated to a reference). But quantum mechanical superpositions, whose probabilities correlate exactly with classic experiments, are not correlated to a reference. Explaining E. Schrödinger's 1935 tongue-in-cheek thought experiment demonstrates that correlation to a reference is required to transform the probability distribution represented by a superposition into a measurement.

Schrödinger's Thought Experiment[4]

"One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following diabolical device (which must be secured against direct interference by the cat): in a Geiger counter, there is a tiny bit of radioactive substance, *so* small, that *perhaps* in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives *if* meanwhile no atom has decayed. The first atomic decay would have poisoned it. The ψ function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts."

Discussion

Schrödinger's experiment first appears to contrast two observables, the probabilistic time distribution of an atom's state and a cat's binary state (alive or dead) by correlating two observations (measurements): an atom's decay and a cat's death. In fact, by virtue of the apparatus the actual time of each cat's death is fixed to the time of the atom's decay. Schrödinger proposed the mean of these distributions is one hour. With a mean of one hour the total atom's decay time distribution is estimated to be 2 hours.

Next, Schrödinger proposed one observation of the cat's state by a human at one hour. This is one observation of a third distribution of the observed cat's state. This may be compared with the actual cat's state (first and second distribution). This comparison is more interesting as it describes a measurement of a cat's state.

The third distribution of each cat's observed time of death is correlated both to the actual time of death and to how often does the human observe the cat (i.e., the time-between-observations). In Schrödinger's experiment this time-between-observations is given as one hour. Since it is one hour to the mean of the distribution of every cat's time of death, the accuracy of this one observation is +/- one hour (2 hours total) relative to every cat's actual time of death.

The metrology[1] variable accuracy is adjusted by calibration which correlates the measuring apparatus intervals (in this experiment, the time-between-observations) to a time reference (e.g., one second). The reference here may also be seen as a non-local intermediate required to maintain Euler's quantity ratios.[2]

When the times proposed (both one hour) are applied, the distribution of the time-between-observations is independent of the distribution of the atom's decay time, so there is no relationship. This occurs because the accuracy +/- one hour, of the time-between-observations, is as wide as the atom's decay distribution (2 hours). For this reason this thought experiment does not identify any other relationships than the fixed one.

However, this experiment has drawn interest for 85 years because of what occurs when the human's time-between-observations is more appropriate.

Development

The first human observation of a dead cat after an observation of life is measured in time from the beginning of the experiment (alive cat). These observations of the time of death identify that the distribution over multiple experiments is correlated with the ψ function of an atom's probabilities and that the state of each cat is binary. The actual time of death and the observed time of death are different. The observed time of death is also correlated with the time-between-observations and the time reference defined.

Applying the theory of quantum mechanics, J. von Neumann's Process 1[5] (a projection of unit vectors), transforms an atom's ψ function into the probability distribution of each time of a cat's death (fixed to the atom's decay). Consider this transform a measure (uncorrelated to a reference). In this experiment, Process 1 effectively counts the number of times an observer (or measuring apparatus) examines a cat. These observations result in a sequence of alive states ended by one dead state during the 2 hour time to complete one experiment. Counting each alive observation before a cat's death generates a magnitude, but not a measurement correlated to a time reference. This measurement requires defining and controlling the time-between-observations, which requires calibration to a time reference.

As example in Schrödinger's experiment, calibration would be setting and maintaining the time-between-observations to 10s (s = second, the time reference or unit). Then the maximum variation of the observed time of death relative to the actual time of death is +/-10s (accuracy). Through calibration, a count of the time periods between observations, which were uncorrelated, becomes a sum of multiple time-between-observations each correlated to a time reference.[6] Calibration is required, but not included in Process 1, to observe accurately a cat's time of death (i.e., a measurement). Correlation to a reference is also not included in Schrödinger's ψ function or wave equation. Therefore there cannot be one ψ function, as Schrödinger proposed, of the actual cat's state and the observed cat's state. Life and death remain binary.

Conclusions

In all physical measurements, calibration to a reference reduces the variation of the sum of the slightly different magnitudes of each measurement unit of a physical measuring apparatus. Calibration is also required to correlate each measurement unit to a physical reference(s).

The accuracy of a measurement is established by the smallest calibrated unit of the measuring apparatus. This is an extension of the Planck unit of action which is the limit of the accuracy of any measurement. In quantum mechanics theory the reference is a local unit vector. Thus the measure of a superposition is a probability distribution. When a physical reference is applied via a measuring apparatus to a superposition, the superposition vanishes and a classic measurement occurs. When a reference is considered, measurements in quantum, classic and relativistic physics are consistent. Schrödinger's ψ function remains a complete description of reality, before any observation.

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[1] *International Vocabulary of Metrology* (VIM) 3rd edition, BIPM JCGM 200:2012, http://www.bipm.org/en/publications/guides/vim.html This provides definitions of accuracy, calibration and unit.

[2] L. Euler, *Elements of Algebra*, Chapter I, Article I, #3. Third edition, Longman, Hurst, Rees, Orme and Co., London England, 1822. "It is not possible to determine or measure one quantity other than by assuming that another quantity of the same type is known and determining the ratio between the quantity being measured and that quantity".

[3] A. Einstein, Relativity, Crown Trade Paperbacks, New York, NY, 1961, p67. "Every motion must be considered only as a relative motion."

[4] E. Schrödinger, "The Present Situation in Quantum Mechanics". First published in German in Naturwissenschaften 23, 1935. This translation (J. D. Trimmer) first appeared in the *Proceedings of the American Philosophical Society*, 124, 323–38 (1980).

[5] J. von Neumann, *Mathematical Foundations of Quantum Mechanics*, Princeton University Press, Princeton NJ, USA, 1955. Process 1 is formally described on page 351.

[6] K. Krechmer, Relative Measurement Theory, The unification of experimental and theoretical measurements, *Measurement*, Volume 116, February 2018, pages 77-82. https://www.sciencedirect.com/science/article/pii/S0263224117306887