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New adventures with Schrödinger's cat: The role of statistical uncertainty in stabilizing measurement

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Abstract: We reopen Erwin Schrödinger's thought experiment involving a cat in an informationally impenetrable box. A common view is that the cat enters a superposition of alive/dead because of a lack of observation, leading to uncertainty about the state of the cat. We, on the other hand, argue that the cat only enters a superposition if everything about the cat is known prior to the box being closed. The superposition results from a *lack* of uncertainty inside the box. Rather than interpreting this state of affairs as a live and dead cat interacting with each other, we suggest that the more natural interpretation is that of an inability to precisely position events within spacetime due to the lack of uncertainty. We clarify how stable measurement depends on a diversified portfolio of statistical uncertainty, and how the lack of such uncertainty in Schrödinger's box precludes stabilization. © *2017 Physics Essays Publication*. [http://dx.doi.org/10.4006/0836-1398-30.2.232]

Résumé: Nous rouvrons l'expérience mentale d'Erwin Schrödinger impliquant un chat dans une boîte informatiquement impénétrable. Une opinion commune est que le chat entre dans une superposition de vivant/mort à cause d'un manque d'observation, menant à l'incertitude de l'état du chat. Nous, d'autre part, soutenons que le chat n'entre pas dans une superposition que si tout est connu au sujet du chat avant que la boîte ne soit fermée. La superposition résulte d'un manque d'incertitude à l'intérieur de la boîte. Plutôt que d'interpréter cet état de choses comme un chat vivant et un chat mort interagissant entre eux, nous suggérons que l'interprétation la plus naturelle est celle d'une incapacité à positionner avec exactitude les événements dans l'espace-temps. Nous précisons comment une mesure stable dépend d'un portefeuille diversifié d'incertitude statistique et comment l'absence d'une telle incertitude dans la boîte de Schrödinger empêche la stabilisation.

Key words : Quantum Mechanics; Metrology; Stability; Systematic Uncertainty; Statistical Uncertainty; Diversification; Aggregation; QBism; Consistent Histories; Many Worlds.

I. INTRODUCTION

Measurement is the idea of expressing uncertainties relative to some standard, thereby enabling accurate predictions to be made about the relationships between them.[1,2] For example, if the length of a desk is measured by a tape, and a doorway is subsequently measured by the same tape, then a prediction can be made as to whether the desk will fit through the door.

For measurements to support accurate predictions, they should describe properties that are *independent* of other environmental variables.[1] This allows a model of the measured property to be developed, without needing to worry about the context in which the measurements were taken. For example, I can measure my desk and use that measurement to predict whether the desk will fit through the door, without needing to worry about what day of the week it is. If I measure my desk on Monday, and my office door on Tuesday, I expect to be able to relate the two measurements directly, despite the fact they were made on separate days: a reliable measurement of length should be independent of the day on which it was made.

Properties such as distance and time intuitively stand out as being independent of the context in which they are measured. Nevertheless, in 1905 Einstein realized that, although seemingly quite separate in everyday experience, space and time are not completely independent. He argued that the notion of space-independent timing (i.e., simultaneity) is incoherent, because the two dimensions are actually connected. By clarifying the nature of the relationship between space and time, Einstein arrived at an even more independent meta-property of nature, which he called "absolute spacetime."

But how do we ensure that measurements of spacetime are truly independent of measurement context? How can we tell when they are not? We begin by examining the property which measurement standards are designed to meet, a property known in metrology as "stability."

II. MEASUREMENT STABILITY

Metrology is the science of measurement and standardization, carried out by professional metrologists, who are experts in maximizing stability.[3] Stability refers to the tendency of an apparatus to produce the "same" measurement outcome over repeated runs, as well as replicating the outcomes of similar instruments around the globe. Ideally, measurement readings should not be associated in any way with the location or moment in which they are taken. Standardization can be regarded as a process for ensuring independent agreement: despite being displaced in space and time, and having no causal interaction with each other, metrological laboratories can produce results which agree with each other. Under the guidance of the Bureau International de Poids et Mesures (BIPM), a worldwide network of metrological institutions is responsible for comparing, adjusting, maintaining, disseminating, and refining these stable standards.[3]

One of the notable successes of these institutions is the standard measure of time used in almost every scientific context, known as Coordinated Universal Time (UTC).[3] UTC is regarded as overwhelmingly stable insofar as a number of standardization labs around the world manage to closely reproduce it on an ongoing basis. In practice, what this means is that they are able to make highly accurate *predictions* about how clocks will behave in different circumstances in different parts of the globe each day.

A common assumption about measurement is that stability is achieved by eradicating uncertainty. Nevertheless, Maguire *et al*.[1] have argued that, in practice, accurate measurement depends not on reducing uncertainty but on enhancing it, by aggregating multiple independent sources of uncertainty. To appreciate this dynamic, we must consider the difference between accuracy and precision.

III. MEASUREMENT ERROR

The stability of UTC is a reflection of its very low predictive error, otherwise known as "measurement error." Metrologists identify two types of measurement error, namely, *statistical error* (which lowers precision) and *systematic error* (which lowers accuracy).

Statistical error is the type of predictive uncertainty which exists between a single measurement and the average of a larger group of measurements. In other words, it is the type of error which can be reduced by taking many measurements and averaging them, rather than relying on a single one.

The foot, for instance, is an ancient unit of measurement based on the human body. As we know from experience, human feet vary in length: one person's foot only predicts the length of another person's foot to a limited degree of precision. In response, medieval surveyors came up with an ingenious idea. They would line up 16 randomly selected people, measure the combined length of their feet, and divide the total into 16 foot-long segment.[4] A 16-way average predicts another 16-way average much more precisely than a single foot predicts another single foot (the expected deviation is reduced by 75%). This is an early example of a powerful technique for reducing statistical error that statisticians refer to as "aggregation."

The other type of error, known as "systematic uncertainty," is the type of uncertainty which cannot be reduced by aggregation. Systematic errors are those that cannot be detected through statistical analysis of repeated measurements, because they remain stable under repetitions. An example of a systematic error in the case of the medieval foot would be if the 16 people chosen to line up were not random specimens of the population. For instance, just taking the 16 people closest to hand might result in 16 adolescents or 16 women being used to estimate the foot length. Increasing the sample to 32 or 64 in this case would not improve the accuracy, because the error is due to a lack of diversity in the sample, not the size of the sample.

Statistical uncertainty is easily controlled by aggregating multiple independent sources. Systematic uncertainty, on the other hand, is much more difficult to bring under control. Maguire *et al*.[1] have argued that, in practice, the best indicator of low systematic uncertainty is high-quality statistical uncertainty, which, though imprecise, is highly accurate. The imprecision can be easily addressed through repeated sampling.

Viewed from this perspective, the fundamental goal of metrology is that of maximizing statistical uncertainty.[1] The ideal measurement standard is one whose precision can only be enhanced through further aggregation, and not by any other means. In other words, the ideal measurement standard is one whose uncertainty is purely statistical. As systematic uncertainty is minimized, the remaining uncertainty becomes more and more statistical in nature, making the deviation between repeated measurements less and less predictable.

IV. THE LINK BETWEEN STATISTICAL UNCERTAINTY AND STABILITY

An analogy may be useful here. Imagine there's a newly published Maths proof to be checked. How do we verify that the proof is correct? We can ask a mathematician to verify it. But mathematicians can make mistakes. So we can get multiple mathematicians to check it—the more mathematicians that are involved, the lower the probability that they are all wrong.

Unless that is, they are all making the same mistake. Maybe all of them have been taught in the same school, and feature the same weakness in their reasoning. The safest approach, therefore, might be to elicit the opinions of a diversified portfolio of mathematicians from all over the world, all representing different forms of mathematical uncertainty.[5] The greater the number of opinions, and the more independent they are, the greater the stability of the resulting aggregated opinion (see Ref. 6 for many more real world examples).

Could we not just pick the best mathematician in the world, the one who is always right? But this raises the question—how do we know that one particular mathematician is always right? What standard of correctness is it that they corroborate? We are faced with the same problem, that of establishing a standard in the first place. Always, we are led back to the idea that the ultimate measurement is one that reflects the aggregation of a large number of independent samples (see Ref. 7). Independence is the cornerstone of measurement, not truth, nor the eradication of uncertainty.

For example, UTC, the primary time standard by which the world regulates time, is not derived from a single hyper-accurate clock.[3] Instead, it is derived from a diversified portfolio of units, each of which contributes independent sources of high-quality statistical uncertainty. The

UTC standard reflects a weighted average of the timing kept by more than 400 atomic clocks in more than 50 national laboratories distributed worldwide. These clocks are constantly drifting apart from each other, and the art of deriving UTC from them involves a complex set of statistical processes for isolating and aggregating independent sources of statistical uncertainty. Clocks which drift away from the average are not eliminated from the calculation. In other words, consistency is not used as a criterion for determining which clocks are the "most accurate." Instead, clocks are valued for their individual independence and mutual unpredictability.[3]

The same idea applies to the measurement of spacetime position. Such position must be calibrated relative to that of other events, which are themselves associated with some level of uncertainty. The key to achieving accurate measurement is leveraging a diversified portfolio of these uncertainties. Currently, quantum atomic transition is the most unpredictable, most random, most independent type of event known in physics, as enshrined by the highly successful theory of quantum mechanics. Consequently, a diversified portfolio of atomic transitions can allow positions in spacetime to be pinpointed with unparalleled accuracy and precision.

The link between aggregated statistical uncertainty and stability is evident in the practice of metrology. For example, the BIPM currently defines the second as the duration of 9,192,631,770 cycles of radiation from the caesium-133 atom. Each transition within the caesium-133 atom occurs at an entirely unpredictable moment, leading to unbeatable timing stability when large numbers of these statistically uncertain events are aggregated.

Viewed from this perspective, statistical uncertainty and stability are effectively the same concept, separated only by repeated measurements. It is thus perhaps not a co-incidence that Einstein, over the same three-month period in 1905, discovered that atomic transition provides both an immutable source of statistical uncertainty in the form of individual photons (the quantum photoelectric effect) and, at the same time, immutable stability derived from a large aggregated set of photons (the constant speed of light). In effect, Einstein was saying that we do not have a concept of timing accuracy beyond the behavior of light, thus light cannot be interpreted as having a variable speed.

We propose that because the concept of timing *precision* depends, not on a single photon, but on a diversified portfolio of independent photons, spacetime cannot be absolute. The appearance of continuity it is a statistical effect that averages out from the aggregation of large numbers of independent quantum events, and yet, it does not apply to those events in isolation. In Sec. V, we argue that a lack of uncertainty inside Schrödinger's box serves to highlight the failure of absolute spacetime as a model of reality.

V. THOUGH EXPERIMENT: VIDEOING SCHRÖDINGER'S CAT

In brief, the central premise of this section is that the Schrödinger's cat paradox emerges, not due to a lack of certainty about the cat, but due to the lack of independent sources of statistical uncertainty inside the box, on which the stable measurement of spacetime depends.

As previously argued, measurement stability emerges, not from the eradication of uncertainty, but from the aggregation of large numbers of individually unpredictable events, such as independent atomic transitions. When such sources of uncertainty are not available, the concept of absolute spacetime breaks down, and the underlying quantum nature of reality is exposed.

Quantum mechanics is often described as deeply counter-intuitive, but we can break down this failure of intuition down into four separate forms:

1. **Time-based superposition**—This involves what intuitively should be a discrete point in time (i.e., an event) being smeared out over a section of time. Schrödinger's cat provides an example of this phenomenon (when exactly did the cat die?)
2. **Space-based superposition—**This involves what intuitively should be a discrete point in space (i.e., a particle) being smeared out over a section of space. Young's double slit experiment provides an example of this phenomenon (which slit did the particle travel through?)
3. **Space-based entanglement—**This involves what intuitively should be dispersed locations in space being unified into a point in space. For example, a pair of connected particles is separated before being measured, causing a seemingly instantaneous connection across space. Einstein *et al*.[8] referred to this as "spooky action at a distance."
4. **Time-based entanglement**—This involves what intuitively should be dispersed locations in time being unified into a point in time. For example, delayed choice experiments (e.g., Ref. 9) have confirmed the ability of measurements made on photons in the present to alter events occurring in the past, without violating causality.

Even more exotic scenarios can be created by combining different forms of entanglement and superposition together to yield further convoluted scenarios. Yet no matter how counter-intuitive, the predictions of quantum theory always hold.

What causes these weird quantum effects? Our view is that quantum effects emerge due to a *lack* of independent sources of statistical uncertainty, leading to a failure of the measurability of spacetime. The "collapse" of a superposition is what happens when an isolated event is abruptly stabilized by many sources of independent statistical uncertainty in the environment.

Let us now consider this proposal from the perspective of Schrödinger's thought experiment. The scenario involves the idea of placing a cat into a time-based superposition, so that it is both dead and alive at the same time (we do not know when the death occurred [50%] or if it has occurred yet [50%]). In 1935 Schrödinger wrote to Einstein:

> *"One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following 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 the 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 that 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 psi-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."*

This thought experiment poses the question of when exactly a quantum system stops existing as a superposition of states and "collapses" to become one or the other. Many questions come to mind. For instance, what does the cat see? In what sense can the live cat be "interacting" with its dead self? And why does opening the box have the effect of banishing one of the cats? (a.k.a. the measurement problem).

Einstein was impressed with Schrödinger's idea and stated his confidence in the absolute nature of spacetime:

> *"Nobody really doubts that the presence or absence of the cat is something independent of the act of observation."*

We argue that the key to understanding this apparent paradox is that, because spacetime must be stabilized by an aggregated portfolio of independent statistically uncertain events, single events in isolation have no stable position. Thus, the status of the cat in the box cannot be defined using the spacetime model.

In the same way, it is not possible to describe the pattern of drift of a UTC clock once it is isolated from the rest of the globally distributed UTC set. While the magnitude of drift can be established once contact is renewed, the manner in which the drift evolved over time is undefined (e.g., was it a constant drift or a sudden divergence?) Any event timed by a single, isolated, UTC clock is smeared over UTC time, just like the death of Schrödinger's cat is smeared over absolute spacetime. An event recorded by a single UTC clock does not have a predictable ordering relative to other events timed by a diversified set of UTC clocks.

VI. GETTING A CAT INTO A SUPERPOSITION

Putting Schrödinger's cat into a superposition means putting it into a state where the timing of the poison release cannot be stabilized by independent sources of statistical uncertainty within the box. If an ordinary cat was taken off the street and shoved into a box which was entirely sealed off from the rest of the universe, it would not go into a superposition. Upon opening the box and finding a dead cat, it would be possible to tell exactly the moment at which the cat died. In this case, the apparently random timing of the poison release would have been stabilized by other independent sources of statistical uncertainty in the box, such as, for example, thermionic emission from the cat's body. If the cat happened to be alive, there would be no evidence whatsoever of a superposition with any dead cat.

So what would it take to put a cat into a genuine superposition, as per Schrödinger's idea? As well as sealing the cat off from the world, we would need to extract all of the unpredictability from the box, except for the single radioactive decay event that triggers the poison release. Under these conditions, the contents of the box have no relationship with any other source of independent statistical uncertainty until the box is opened. With no source of uncertainty left, the "moment of death" is a concept which is undefined relative to the concept of absolute spacetime.

In this scenario, we know absolutely everything about the cat. Nothing is unpredictable. Therefore, counter-intuitively, nothing in the box can be used to infer what happened. There is no independent statistical uncertainty left in the box relative to which the unfolding of events can be stabilized. When we open the box, all we learn is whether the poison has been triggered or not, nothing about "when" it happened. Surprisingly, knowing more about the cat means you know less precisely when it died.

An analogue can be identified here between Schrödinger's cat and Heisenberg's uncertainty principle. According to Heisenberg, the more precisely the position of some particle is determined, the less precisely its momentum can be known, and vice versa. Otherwise stated, the position of a particle can only be stabilized relative to the uncertainty of its momentum, and vice versa. It is the same situation with Schrödinger's cat. The moment of death of the cat can only be stabilized by uncertainty in the state of the cat. The more we know about the state of the cat, the less precisely we know its moment of death.

VII. INTRODUCING THE VIDEO CAMERA

We have proposed that if there are no independent sources of statistical uncertainty left in Schrödinger's box, then there is no means of recording the events that unfold in the box, meaning that spacetime is undefined. This still seems counter-intuitive. Let's get more adventurous, this time by putting a video camera into the box with the cat. We are going to video what happens. Now we should be able to see the moment at which the cat dies.

We open the box, find a dead cat, and take out the video camera. What happens when we play the tape back? If the cat was just an ordinary cat taken off the street, then the video camera can show us a recording of exactly what happened, revealing the precise instant of death. However, if the cat was precisely measured before being placed in the box then all we see is…nothing. Without any independent sources of statistical uncertainty to stabilize the concept of spacetime, the video camera cannot lay down a recording which would allow the timing of events to be inferred.

When we play the video tape all we see is darkness. But of course! That should be easy to resolve, we simply forgot to put a light source into the box along with the video camera.

A light source, however, is a source of statistical uncertainty. It radiates photons, the release of which is unpredictable. This uncertainty serves to stabilize, or "illuminate" events, permitting a recording. If we insist that the contents of the box be free of statistical uncertainty, as per Schrödinger's idea, then there can be no light, and the video camera records nothing but darkness.

How about using a thermo-imaging camera that does not require a light source in the box? But now we are relying on the cat giving off heat, which is another form of radioactive decay, and an alternative source of statistical uncertainty. If the cat was perfectly measured so as to eliminate all sources of unpredictability, then the cat would no longer radiate any heat. It would exist in a state of suspended animation, for which absolute spacetime ceases to be defined.

What this thought experiment reveals is that the concepts of "recording" and "superposition" are opposites of one another. The capacity to record information presupposes stabilization (i.e., the absence of any superposition). For example, a clock is a mechanism that integrates large numbers of random events to yield a "stable" reading. In contrast, a superposition is a state that features a lack of such statistical uncertainty, thus rendering the concept of time meaningless. Superpositions violate the notion of absolute spacetime, meaning that a "clock" placed in a superposition is no longer a clock, because it records no timing (see Ref. 10). An object which is perfectly measured, and quarantined from all sources of statistical uncertainty, does not evolve in time (see the Turing paradox or quantum Zeno effect; e.g., Ref. 11).

Do the dead cat and live cat interact in some way? For a start, it is not the case that there is one dead cat interacting with one live cat. The time-based superposition is between the live cat (50%) and an infinite number of dead cats, which have died at every possible moment. An easier way to picture this scenario is simply that the timing of events in the box cannot be recorded. When the box is closed, the cat ceases to be precisely positioned within spacetime. During the following hour the poison atom either decays or not, but the cat itself does not "happen." What the superposition means in practice is that no information about timing can ever be derived once the box is opened.

In relation to his problems accepting quantum effects, Einstein is reported to have asked a colleague "Do you really believe the moon is not there when you are not looking at it?" More pertinently, with an eye on metrology, he might have asked "do you really believe the moon is not precisely positioned in spacetime when there is no available means of precisely recording its position?" Spacetime is something that has to be measured, and stable measurement depends on a diversified portfolio of independent statistically uncertain events, each of which, taken in isolation, has no precisely defined position. In conclusion, it is the independence of atomic transitions that forms the building block of reality, not absolute spacetime.

VIII. RELATIONSHIP TO OTHER INTERPRETATIONS OF QUANTUM MECHANICS

Although the predictions of quantum mechanics are perfectly matched with empirical observations, there are numerous different interpretations which aim to explain how quantum mechanics fits in with our intuitive understanding of nature. In this section, we explore the similarities between our view, which we henceforth refer to as "metrologism," and alternative views, namely, QBism, consistent histories, and many worlds.

A. QBism

Quantum Bayesianism, or QBism, is a subjective Bayesian account of quantum probability derived from the Copenhagen interpretation, drawing from the fields of quantum information and Bayesian probability.[12] The central idea is that quantum effects arise because different observers experience different subjective probabilities which cannot be directly compared. QBism rules out the view from nowhere, the idea of an agent-independent description. According to Schack,[13] "people have a fundamental creative role in the world:" reality is built on what observers know, rather than being founded on outcomes that pre-exist measurement.

The fundamental idea behind QBism, namely, that counter-intuitive quantum effects arise because of a lack of agreement, is compatible with metrologism. What metrologism adds, however, is an explanation of how exactly objective measurement is achieved, namely, via the aggregation of multiple independent sources of statistical uncertainty. One key difference between these two accounts is that, according to the metrological view, quantum mechanics has nothing whatsoever to do with people, it has to do with statistical uncertainty, specifically the reliance of stable measurement on a diversified portfolio of uncertainties. The precision with which measurements can be carried out greatly transcends the level of human interactions, making it next to impossible that two people would disagree on a measurement reading because of differences in subjective opinion.

Whereas QBism focuses on different people experiencing different subjective probabilities regarding Schrödinger's cat, the metrological view focuses on how the lack of independent sources of statistical uncertainty inside the box eliminates the possibility of stable measurement. There are no people involved in the explanation.

According to Mermin,[14] "QBism attributes the muddle at the foundations of quantum mechanics to our unacknowledged removal of the scientist from the science." Metrologism disagrees: scientists and their subjective opinions have nothing to do with the stabilization of spacetime. Quantum mechanics instead relates to the foundations of measurement itself.

B. Consistent histories

The *quantum decoherence*, or *consistent histories* perspective is one in which the Copenhagen notion of objective measurement does not feature. Instead, the approach provides an account of how a quantum system transitions to a mixture of states that appear to an observer as if a superposition has collapsed.[15–17] Over time, superpositions will "leak" information into the environment, becoming decoupled from the quantum system and eventually acquiring phases from their immediate surroundings. According to consistent histories, all systems remain probabilistic, and classical mechanics emerges as a useful approximation of the more fundamental quantum mechanics.

This interpretation is very close to the metrological perspective, which views stabilized spacetime as the relationship between a diversified portfolio of statistical uncertainties. The one subtle difference between consistent histories and metrologism is that the latter view explicitly acknowledges the role of statistical uncertainty in the stabilization of measurement, thus treating quantum effects not as a fundamental theory of reality, but as an intrinsic feature of measurement itself. Quantum mechanics emerges because of how humans think about measurement. If at some stage it turns out that atomic transitions are somehow predictable, and a deeper, purer source of statistical uncertainty is identified, then the same quantum effects will once again emerge.

C. Many worlds

One interpretation which is not at all compatible with metrologism is the many worlds interpretation. This view, proposed by Hugh Everett in 1957, assumes that quantum effects are objectively real, implying that all possible alternative histories and futures are real (see Ref. 18).

Many worlds persists with the notion of an absolute spacetime that exists beyond measurement, an undefined view from nowhere. It is vague about determining how and when "splitting" happens. For example, the interpretation of the Schrödinger's cat thought experiment is that both alive and dead states of the cat persist after the box is opened, but are split into different noninteracting universes. We start off with a single cat in the box. However, over time the "measurement" of the poison atom "splits" this cat into an infinity of cats, all interacting together in the box, 50% of which are alive, and 50% of which have died at different moments in time. After an hour, opening the box, and allowing this group of cats to interact with the environment, causes different degrees of splitting within the cat group into various levels of independent separation. And so forth.

How does the splitting happen? When does the splitting happen? How can we verify that splits have occurred? If splits are beyond measurability, then what is the sense in representing their existence? We can see that this view quickly becomes laborious and unproductive. In direct opposition to the metrological view, the many worlds interpretation simply delays confronting the fundamental problem of understanding the foundations of measurement.

IX. CONCLUSION

We have proposed that, contrary to intuition, measurement is not about eradicating uncertainty. Instead, it is about expressing one source of uncertainty in terms of a diversified portfolio of independent sources of statistical uncertainty. As a result, the key challenge of enhancing predictive accuracy becomes that of identifying a random, unpredictable physical phenomenon on which a measurement system can be grounded. The dependence of measurement on a diversified portfolio of such random events gives rise to quantum effects at the limits of precision. As we have seen, adopting the metrological perspective allows clear predictions to be made regarding the conditions needed to place Schrödinger's cat into a superposition, and what will be observed in the box once it is opened.

Metrologism supports several interesting insights about the relationship between spacetime and the underlying quantum reality. For a start, it highlights the fact that superpositions depend on ultraprecise measurements which suppress internal sources of statistical uncertainty. In light of this requirement, putting large objects into superposition will be extremely challenging. For any organism with a brain (e.g., Schrödinger's cat), putting it into a superposition will be at least as difficult as measuring the organism's brain precisely, thereby allowing every aspect of the organism's behavior to be predicted. This may not be feasible in practice.[19]

Metrologism holds that events do not have an intrinsic positioning within spacetime. Instead, such positioning is a feature that emerges once the event happens to be "illuminated" by a diversified portfolio of statistical uncertainties (e.g., unconnected sources of atomic radiation). The concept of absolute spacetime is nothing more than a convenient heuristic, which can be defined to a limited degree of precision.

Most importantly, metrologism reveals that the concept of spacetime is intrinsically connected to the availability of statistical uncertainty. If a perfectly measured clock is placed in a Schrödinger box, and sealed away from the rest of the universe, it stops ticking completely, because of the lack of uncertainty required to stabilize its passage through time. We suggest that formalizing the process by which spacetime is stabilized, and the manner in which this influences its geometry, has the potential shed light on some of the deepest questions in physics.

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