On the Deterministic Roots of Indeterminacy

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Abstract: *Undecidability, uncomputability, and unpredictability are outcomes not of mathematics* per se*, but of how classical physics and its most refined subset, mathematics, emerge from the quantum world. Since all three are assertions of an inability to create certain classes of information, their full resolution requires a deeper, more physics-based definition of the relationship between information and reality. In this essay I propose a variant of quantum decoherence theory in which the deepest and most fundamental driver beneath quantum and classical theory is multi-level emergence of virtual pairs, with higher level pairs including half-pair parts from lower, more fundamental pairs. The virtual pairs of particle physics are explicit examples of one of the highest levels of this phenomenon. All virtual pairs at all levels must sum to exactly to null, a return to the void. However, since higher-level pairs must first cancel out all of their lower-level components before they can return to the void, there exists within the generalized pair production mechanism a small window of opportunity for the emergence of both quantum and classical reality. This window opens up when halves of related but non-identical pairs attempt to cancel each other out. The partial cancelation leaves both pairs in a state of temporary limbo until the appropriate cancelation quantities can be found. Hydrogen atoms, the foundation of our universe, are examples of this type of incomplete cancelation for the case of electric charge. Decoherence theory comes into play next, but in a very specific fashion: Recombination of two mismatched pairs will be prevented only if one of the halves becomes so complexly entangled — so thermally entangled — with other similarly stabilized pairs that the probability of return to null falls effectively to zero. The first such indefinitely persistent pair half constitutes the first bit of* information*, and with it the beginning of classical history and classical physics, because that is all that classical physics, including space and time, is: bits. Mass-energy is the most persistent of all bit types because its negation is hurtling away from us in reverse time as another universe, the other half of a virtual universe pair. Mass-energy, not spacetime, is the most fundamental entity of our universe, with time and space reduced to finite granularity state machine operators that ensure absolute null sums despite thermodynamic chaos. Three-space is for example the set of operators that ensure absolute conservation of angular momentum across the universe, including quantum entanglement as needed. This also answers the status of both undecidability and uncomputability: both theorems are simply invalid due to their inclusion of recursive self-examination steps that flatly incompatible with finite-granularity, one-direction-only time operators. They simply loop, and so prove nothing. Unpredictability, however, becomes an intrinsic and unavoidable result of the finite nature of the universal state machine. Quantum uncertainty is an illusion generated by the finite granularity of the always-finite bits-based classical world. The quantum world in contrast remains fully deterministic in its drive to maintain a universal null.*

A Physics-First View of Mathematics

Philosophers have debated for centuries if not millennia about the relationship between mathematics and the physical world, and that is a pretty good hint that it is best not to try to resolve that issues in a short essay. On the other hand, I think it's also safe to say that physics and mathematics undeniably have a very close and special relationship. Thus without pretending it to be a resolution, I would at least like to suggest this idea: Mathematics can with some safety be viewed, at the very least, as the most refined and abstract version of physics, the version of physics in which minds are able to explore reaches far beyond those of everyday experiment.

Just look at what mathematics has done for cosmology and quantum mechanics, enabling explorations on paper that will in many cases never be achieved, at least not through any physics of which we are currently aware. Yet it is not limited just to the boundaries of known physics, enabling for example the quantified exploration of universe that are not like ours, yet *could* exist as best we can tell, in some other part of reality. That is a powerful set of tools!

The focus of this essay, however, is whether and how three mathematical ideas — undecidability, uncomputability, and unpredictability — are fully in keeping with *this* universe as we find it. I freely and cheerfully admit that this is a constraint that others might feel unnecessary or even invalid, but the advantage of this approach is that it at least makes concept *operational*, that is, meaningful in ways that we can both understand and analyze in more detail. The pool of physics is deep, and can provide important insights even to what might seem at first to be purely mathematical questions. And finally, who is to say that a deeper analysis of how our reality works may well provide insights into the nature of mathematics itself?

The Forbidding of Information

Undecidability, uncomputability, and unpredictability are all assertions of an inability to create certain classes of information. To *decide* is to create information that irreversibly alters the set of future paths available under the laws of physics. Similarly, to *compute* is to create information, a set of bits, that once again alters the future forever, even if such changes initially apply only within the confines of a computer storage device. Finally, to *predict* is to compute how aspects of some other system will evolve in the future. Undecidability, uncomputability, and unpredictability thus are all three assertions of the *inability* in specific situations to decide, compute, or predict desired information.

Thus it is not really possible to understand undecidability, uncomputability, or unpredictability without first understanding the deeper nature of *information*. Their resolution thus requires a deeper, more physics-based definition of the relationship between information and reality. Thus a physics-based definition of information is the first quest of this essay, from which will emerge a more precise understanding of what information is or is not forbidden. However, the reader should buckle up, then, since it also means that in just a few pages it is first necessary to propose specific mechanisms for the trio of quantum mechanics, classical mechanics, and pure information are related to and derive from each other.

A Quick Glance at Quantum Decoherence

One of the many schools of quantum interpretation is called *decoherence*. While not as flashy as concepts such as the many-worlds interpretation, it has been a popular and pragmatic workhorse of quantum physics since it was first proposed by first in 1970 by Heinz-Dieter Zeh of the University of Heidelberg [1]. The main concept behind decoherence is oddly simple: When analyzing a quantum system, it is *not* a good idea to treat the surrounding "classical" environment as a separate entity. Zeh was first to notice the peculiar defining relationship of the external environment with the details of what states could be superposed in the wave function:

> *"Superpositions of states with different charge therefore cannot be observed for similar reasons as those valid for superpositions of macroscopically different states: They cannot be dynamically stable because of the significantly different interaction of their components with their environment…"*

Schlosshauer in 2005 [2] observed that:

> *"Decoherence has been claimed to provide an explanation for this quantum-to-classical transition by appealing to the ubiquitous immersion of virtually all physical systems in their environment ("environmental monitoring").*

Entanglements, which were more often called quantum correlations in the 1980s, were also a vital part of decoherence. Wojciech Zurek said in 1982 [3]:

> *"Correlations between the properties of quantum systems are more basic than the properties themselves. This order of importance, in which a correlation — a record of a property — comes before the property, reverses the ordinary hierarchy to which one is accustomed within the realm of everyday experience."*

In the 1980s what are now called entanglements more often called quantum correlations. Both the idea that *entanglements* are somehow connected to records — to information — and that entanglements are in some way *more* fundamental than classical properties were quite radical ideas at that time. It was only much later that serious discussion began, for example, on the idea that space itself may be a holographic version of entanglement [4].

Decades later in 2018 Zurek also said [5]:

> *"Decoherence is an ongoing process that continues to extract the selected information about the system and deposit its copies in the environment, where they can be accessed by observers."*

It is at this last point that for the purposes of this essay I must introduce a critical difference in interpretation of the decoherence process, which is this: Instead of saying that information is *extracted* from a quantum system and *deposited* into its classical environment, it is equally possible to interpret the quantum state as a *lack* of information, and the act of observing it the *creation* of information.

This amounts to an image inversion. The all-inclusive white of infinitely many of superposed states in the quantum wave function is transformed into a *lack* of states. The wave function then becomes nothing more than a set of conserved properties whose values must be universally conserved as both the wave function and its immediate environment move into the future. Conversely, the formerly "dark" environment around the wave function, including in some cases points indefinitely distant, becomes the *only* repository for the defining features of the wave function. This is simply the extremum of Zeh's original observation that the environment must constrain ("superselect", to use the term Zeh coined) the states available to the wave function. In this superselection-only interpretation there are *no* inherent states in the wave function. The concept of a point-like particle, which is not allowed experimentally in quantum mechanics anyway, also ceases to exist in theory. It is replaced by an environmentally superselected bundle of conserved quantum properties capable of indefinitely small compression with the addition of sufficient energy. I will call these negative-image quantum waves *dark functions*.

Qubits as Minimal Dark Functions

Any particle with mass-energy is capable of storing information in the form of one or more *states*, the nature of which varies with the particle. To define dark functions of such particles it is necessary to draw a sharp distinction between the *potential* for information and the *actuality* of information. As creatures who live within the confines of classical physics we find such distinctions odd, since we tend to think of entities as always being in some specific state — that is, of always possessing *information*, much like a computer bit always has some physical setting even if we choose to ignore what that setting is.

At the deeper level of quantum mechanics, however, physics has shown unequivocally that particles containing very little mass-energy have strict limits on not only on how many states they can exhibit, but even on whether stay in one of those states indefinitely. In the case of two-states, which at the scale of particle physics are also called *doublet* states, there is a specific term for the case in which an entity can only have two states, and both states are equally balanced. When used in the context of quantum computing, such maximally ambiguous quantum states are also called *qubits*.

In the dark function perspective there simply *is* no information in a qubit. In fact, in the popular *many worlds interpretation (MWI)* of quantum mechanics, it is precisely the conversion of such a qubit by quantum collapse into a 0 or 1 that results the splitting of a universe into two new universes.

The *bit creation interpretation* for dark functions relies on the same math as MWI. Each qubit is "mined" in the sense that its conversion into a bit is once-only event in the history of the universe, a *bit event*. Once such a conversion occurs, half of the previously plausible future histories for our universe are excluded. In MWI these excluded future histories are interpreted as real universes branching off from ours. In bit creation those same universes are excluded, but this time only as *potentials* for futures that can never again be accessed after the bit event takes place.

The Principle of Pair Creation

The bit creation interpretation of dark functions creates a nicely specific definition of information as a serious of *bit events* taking place throughout the universe, with each such event further constraining the range of possible futures of the universe as a whole. But even this quantized version of decoherence is not sufficient by itself to define such dark functions, since the superselection process must still be applied to *something* that needs to be shaped — some bundles of mass, charge, angular momentum, and other absolutely and conditionally charge quantum numbers. What is the source of these, and how do they connect to the superselection environment of the dark function?

At this point I must simply propose a concept, or more specifically, a uniquely broad generalization of a concept known in one form or another every since Newton defined action-reaction pairs. It is the concept of *pair production*, which is seen in its most explicit form in the virtual particle pairs of particle physics. However, the broadest version of pair production is this: Any simple or complex set of quantum numbers can be created as a *pair*, as long as the sum of that pair is exactly null for that same combination of quantum numbers.

Thus action-reaction is a form of pair production because the two momenta created in the simplest case can *in principle* combine back together to give a net sum of exactly zero momentum — as if the momentum had been erased entirely. The sum need not be zero for *all* quantum numbers, only for the number or combination of numbers initially created in the pair. Virtual particle pairs are among the most complex forms of pair production, since from the fabric of space itself they inherit all of the properties — the field excitations — requires to form complex particles, at least for very brief periods.

Fully generalized pair production is multi-level, since for example if an earlier pair event such as an action-reaction pair occurred, then each half of the resulting pair may *itself* undergo further pair productions. Thus an asteroid can split into two parts, and as long as the two parts remain whole, it is conceivable that the two could be rejoined and their momentum pair erased. If however one half of the asteroid is immediately shattered into high-speed pebbles — if it undergoes further momentum pair events on a massive scale — then the statistical odds of the two ever rejoining becomes essentially nil. The chaotic breakup of the one asteroid half has in effect made the momentum of the other half irreversibly "real" and no longer subject to pair reversal. At the same time, the shattering of the other half provides evidence, *information*, about how the other momentum half was created.

Decoherence and Persistence

If you thought I might be suggesting an analogy with the asteroid example, you were correct. The analogy is that a qubit is converted into a real bit is through *asymmetric pair shattering*. The "shattering" in the case of quantum waves monitored by classical equipment is when one-half of some absolutely conserved momentum pair, such as the momentum of a photon reflected from an electron, is irreversibly shattered by colliding with the almost unfathomable complexity of thermal matter. The thermal matter sees the energy and momentum of the photon, and so know that it struck an electron. But the energy and momentum become so entangled with the particles of, say, a rhodopsin molecule in the eye of a human observer that is becomes statistically impossible for that momentum pair ever to be rejoined and put back to null. The electron has been observed, and the momentum it received from the photon has become irreversibly real, *even though the photon may not strike a molecule for eons*, such is in the case of cosmic photons. Such is the power of entanglement: A single photon, tied into the unforgiving quantum fabric of absolute quantum number conservation, can make "real" the location of some isolated molecule in intergalactic space at the other end of the universe — provided, of course, that some *other* photon or particle did not get to it first.

Information as Asymmetric Pair Shattering

The bottom line is that the *information* part of quantum-to-classical transitions — of converting dark function qubits into real, historically recorded bits — comes from asymmetric and thermally complex "shattering" of pairs that sum to void. This pair-shattering variant of quantum decoherence theory enables a surprisingly specific approach not just to the relationship between quantum and classical physics, but on the steps required to create universes with interesting, life-enabling physics.

The deepest and most fundamental driver of both quantum and classical theory becomes multi-level emergence of virtual pairs. These pairs can arise either directly from the void, or higher-level pairs (such as in momentum action-reaction) and emerge from some more fundamental pair (such as rest mass before momentum pair splitting). The virtual pairs of particle physics are examples of one of the highest and most compositionally complex examples of pair production.

Information and Cosmogenesis

All virtual pairs at all levels must sum to exactly to null, a return to the void. However, since higher-level pairs must first cancel out all of their lower-level components before they can return to the void, there exists within the generalized pair production mechanism a small window of opportunity for the emergence of both quantum and classical reality. This window opens up when halves of related but non-identical pairs attempt to cancel each other out. The partial cancelation leaves both pairs in a state of temporary limbo until the appropriate cancelation quantities can be found. Hydrogen atoms, the foundation of our universe, are examples of this type of incomplete cancelation for the case of electric charge.

However, simply producing mismatched pairs is insufficient, since this at best creates only a quantum world in which all the parts eventually find their way back to null. Like virtual particles in the vacuum, it can be lively, but not productive. This is where decoherence comes into play. Recombination of two mismatched pairs can be prevented only if one of the halves becomes so complexly entangled — so thermally entangled, or shattered —that the probability of return of the pair to null falls effectively to zero.

The first such indefinitely persistent pair half constitutes the first bit of information, and with it the beginning of both classical time and classical physics. That is because that is *all* that classical physics, including even space and time, can be in the shattered pair model: bits. We are nothing more than a naturally occurring state machine, a finite set of mutually stabilized historical bits, running on a resolutely deterministic quantum underworld whose overriding goal is to return the entire enterprise back to a nice, quiet null state.

Mass-energy is the most persistent of all bit types in this bit universe, since it is the one case in which its negation, the other side of the pair, is hurtling away from us in reverse time as another universe [6]. Thus it is mass-energy, not spacetime, that is the most fundamental quantity of our universe. In a bit classical universe, both time and are reduced to operators within a finite granularity state machine, ones whose goal is to ensure absolute null sums overall despite thermodynamic chaos.

Space for example become a set of operators whose duties include, among other conservation issues, ensuring the absolute conservation of angular momentum across the universe. At large granularities with lots of bits this operation appears to be smooth and seamless, but as the number of bits available shrinks — e.g. as the mass-energy of the entities grows very small — then intransigence of the underling absolute conservation rules show up as what we call quantum entanglement. It is the entanglement that is precise; it only our view of it as entities within a finite state machine that looks ratty around the edges.

Addressing the Trio of Unknowables

While this extrapolation of decoherence, dark functions, bit events, pair persistence, and paired bit-classical universes may seem like serious overkill for attempting to answer the original question, it is not. By its very nature a bit-classical universe, a state machine universe with finite bits and fidelity even of those chaos-stabilized bits, places severe limits on the types of questions and assertions that can be made about it — and this includes for mathematics, which is after all just another set of bits running on the underlying deterministic quantum conservation platform.

First there are the cases of undecidability and uncomputability. In a universe in which both physics and mathematics are necessarily implemented as finite operators in a forward-time only universe, the recursive self-examination steps that both of these theorems include necessarily unfold into non-convergent loops, a complicated variant of the Liar's paradox. In such a universe, each new iteration of the theorem is no longer the original theorem, but just another failed attempt to access and reset a past that no longer exists.

Unpredictability, however, becomes an intrinsic and unavoidable result of the finite nature of the universal state machine. Quantum uncertainty is an illusion generated by the finite granularity of the always-finite bits-based classical world. The quantum world in contrast remains fully deterministic in its drive to maintain a universal null.

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