God in the Loop

How a causal loop could shape existence.

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My last article, "Life Through Quantum Annealing" was an exploration of how a broad range of physical phenomena -- and possibly the whole universe -- can be mapped to a quantum computing process. But the article simply accepts *that* quantum annealing behaves as it does; it does not attempt to explain *why*. That answer lies somewhere within a "true" description of quantum mechanics, which is still an outstanding problem.

Despite the massive predictive success of quantum mechanics, physicists still can't agree on how its math corresponds to reality. Any such proposal, called an "interpretation" of quantum mechanics, tends to straddle the line between physics and philosophy. There is no shortage of interpretations, and in the words of physicist David Mermin, "New interpretations appear every year. None ever disappear." Am I going to throw one more on that pile? You bet.

I'm not going to start from scratch though; I simply propose an ever-so-slight modification to an existing forerunner: the many-worlds interpretation, where other "worlds" or timelines exist in parallel to our own. My modification is this: the only worlds that *can* exist are those that exist within a causal loop. Stated another way: our universe, or any possible universe, must be a causal loop.

I will introduce the relevant concepts and provide an argument for my proposal, but my goal is not to once-and-for-all prove this interpretation as true. Rather, my goal is to explore what happens if we accept the interpretation as true. If we start with the assumption that only causal loop universes can exist, then several interesting things follow -- we find parallels to our own universe, and we might even find God.

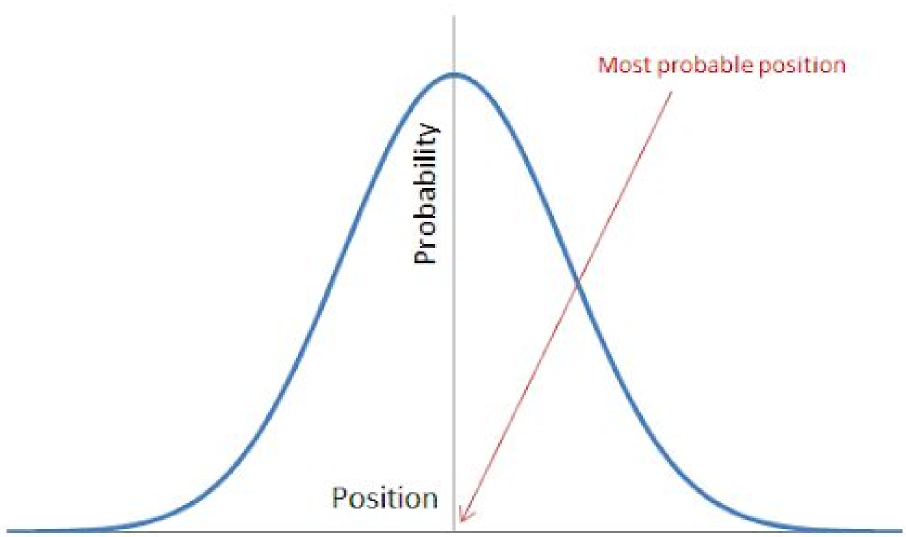
CAUSALITY & QUANTUM INTERPRETATIONS

Before talking about causal loops, let's take a step back and talk about causality -- perhaps the single most fundamental concept in all the sciences. It plays a starring role in the two most important theories in physics: general relativity and quantum mechanics.

General relativity, developed by Einstein, combines space, time, and gravity in a geometric description of spacetime. In spacetime, two observers might not agree on the space between two events or time between two events -- but they *always* agree on the spacetime interval, which corresponds to a causal relationship between two events. As such, *causality* is the only thing that is universally agreed on, making it the only proper description of objective reality. Another phenomenon predicted by general relativity is the cosmic speed limit -- the speed of light -- which is more appropriately understood as the speed of causality, more fundamental than light alone. Here we see that spacetime and the speed of light are not inherently real; they are just useful ways of describing causality, the only objective reality.

But if general relativity is interesting because we can *only* agree on causality, then quantum mechanics is interesting because we *can't* agree on causality.

As I alluded to earlier, the full explanation of quantum mechanics is still a mystery, and that mystery has everything to do with causality -- specifically how objective, causal reality relates to the wave function. The wave function of a quantum system is most easily understood as a probability distribution, where the probability of the system being in any given state is calculated when you square the amplitude of the wave function for that state. The wave function is in a "superposition" of all possible states until it is measured, after which we observe a single state.



Simple depiction of a quantum wave function with a single crest. (Image by Louay Fatoohi)

On the surface, it appears that quantum physics is inherently random if it can only be described by probability, and somehow the act of measuring or observing the system causes it to assume an objective state. If you're convinced of this, then you basically agree with the Copenhagen interpretation of quantum mechanics, which posits an interaction between the system and observer that causes the wave function to randomly "collapse." This has been the standard interpretation for a long time, although others interpretations have been consistently gaining steam.

As an alternative, maybe you don't think the universe is random at all -- it's deterministic, but there are "hidden" variables we don't yet know about. In this case, there is no wave function collapse, so we don't need to introduce any extra physics to explain what happens when we observe the system. If you're on board with that, then you just signed up for the de Broglie-Bohm theory, also known as the pilot wave theory.

But maybe you're still not quite convinced. Let's make things even simpler: the universe isn't random, but there aren't hidden variables either. You have the wave function, and that's it -- what you see is what you get. That, it turns out, pretty much sums up the many-worlds interpretation. In this theory, all possible "worlds" described by the wave function *do* exist; we just happen to occupy one of them. While it requires the least explanation, the bizarre implication is that many parallel worlds exist as branches of different possible outcomes.

These three interpretations tend to be the top contenders, and they each take a different approach to answer the question of "what causes what?" The fact that a basic causal structure of physics cannot gain consensus makes this interesting territory, plus it has far-reaching implications. A proper explanation doesn't just account for the non-locality of entanglement or the apparent uncertainty of superposition -- it explains how humans fit into reality.

As observers, do we cause the wave function to collapse? That would certainly seem to elevate the role of consciousness in the causal nature of reality (which has not gone unnoticed by experts and cranks alike). Or is the wave function itself the only causal, objective reality? If so, that's one more reason to believe we're at the mercy of a universe that's indifferent to our existence.

The third interpretation is the one I want to revisit later in this article: the many-worlds interpretation. Keep it in mind. While it appears to threaten our sense of importance and potentially free will, it's not so bad if we just add a twist -- or better yet, a loop.

CAUSAL LOOPS

It may be fairly self-explanatory, but I'll nonetheless define a causal loop as follows: a closed causal chain of events, where each event is the effect of another event on the chain. A simple example is a loop of three distinct events where Event A causes Event B, which causes Event C, which in turn causes Event A -- each event is causally connected to another on the loop, and there is no "first" event. If you start at any one event, the sequence that follows inevitably leads back to the same event as if it caused itself.

Causal loops sound absurd, but their possibility has been successfully defended, particularly by philosopher Richard Hanley in his paper, "No End in Sight: Causal Loops in Philosophy, Physics, and Fiction" (and any mention of Hanley moving forward is in reference to this paper). Hanley points out that causal loops are not logically inconsistent nor physically impossible -- at worst, they simply require grand coincidences. Causal loops as a whole aren't created, they simply exist, and any strangeness about this is merely apparent -- they're in no worse a position concerning the question of why anything exists. Interestingly, Hanley also mentions that the idea of a causal loop universe is taken very seriously in cosmology, and that causal loops are actually *more likely* to occur in a universe like ours which hosts intelligent agents.

Let's unpack that a bit. If intelligent agents discover their universe is indeed a giant causal loop, they may have incentive to maintain the loop they inhabit by causing the very events that lead to their own existence. Furthermore, they can intentionally make events happen that would otherwise require coincidence. But there is nothing coincidental or mysterious about an intentional action; we intentionally do things every day. Hanley notes, "the existence of agency may be the very thing that permits causal loops to obtain."

This is where I'll take it one step further than Hanley: not only are causal loop universes possible, but all possible universes must be causal loops. As I mentioned earlier, I'm going to run with this as an assumption, but I'll still attempt to provide some reasoning.

That reasoning boils down to two propositions: the first is that all events must have causes; the second is that only in closed causal chains do all events have causes. We saw that in a causal loop all events have definitive causes -- other events on the loop. There is no issue. But in an open causal chain (imagine a straight line), one more event is always required to explain causation. We're left with a case of infinite regress, which isn't inherently problematic, but its "openness" implies there must be an event without a cause, which is impossible. Furthermore, any series of causes and effects cannot, by definition, be considered as part of separate causal systems. If we define a universe to be a causal system, then it follows that all universes must also be causal loops, including our universe.

Using a causal-loop-only starting point, we can dive into some pretty interesting things.

DIFFERENT PATHS: CURVED SPACETIME & CLEVER DEMONS

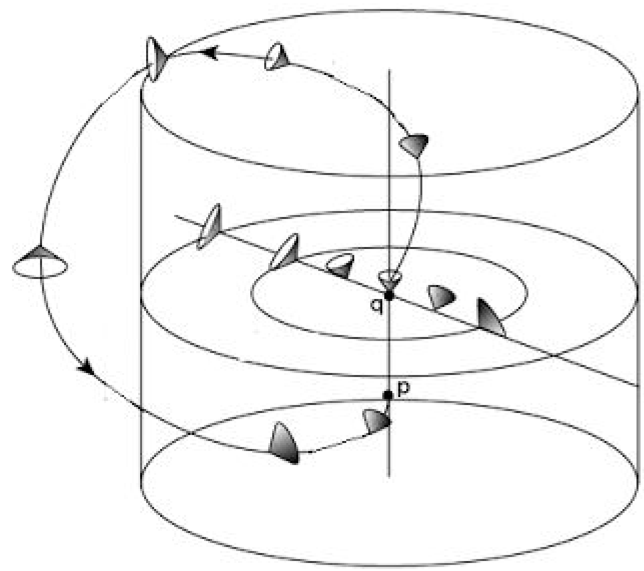
In general relativity, causal loops are permissible in the context of a "block universe." In causal loops, all events in the loop are equally real all the time; they must be for the loop to exist. This closely aligns with a block universe, where all past, present, and future points in spacetime exist "at once"; we simply find ourselves at one point along its progression. In both views, travelling back to the past is possible, but you cannot change the past. If you do travel back to the past though, you may find yourself travelling along a different timeline after that -- which brings us back to quantum mechanics.

You took note of the many-worlds interpretation (MWI) of quantum mechanics, right? If the universe is a causal loop, then whatever interpretation we use must be deterministic since all events along a causal loop are equally real -- they do not spontaneously become real only after another event. Technically any deterministic interpretation suffices to meet that criteria, but I think the MWI best illustrates the range -- and restrictions -- of how possible universes can unfold. The MWI entails the universe "splitting" into alternate histories at every point in time. If we introduce a constraint where only causal loop universes can exist, that directly impacts the range of possible universes we can ever split into. Nothing else about the MWI needs to change; there are still many parallel worlds, but they all must maintain a causal loop. So if we somehow traveled back in time, we may find ourselves splitting into a different looped timeline than before.

Things get interesting when we start to look at possible loops. There are only two ways a causal loop can be maintained in practice: closed timelike curves (CTCs), and reverse causation. While the two entail similarities, they are slightly distinct.

CTCs are theoretically possible in certain solutions of spacetime. One example, popular in science fiction, is a wormhole. In some wormholes, you'll enter one end and exit the other at a previous point in time. But there is serious doubt about whether they could be feasibly traveled through, plus they're just local anomalies. If we're talking about the whole universe, we need to go bigger.

The great logician Kurt Gödel did find one solution to Einstein's equations, now called the Gödel universe, where the entire universe is a CTC. In such a universe, all points in spacetime return to themselves as we'd expect in a causal loop, but it requires that all galaxies have a preferred direction of rotation, for which there is no evidence. When Gödel found his solution, the tools used to study cosmology were not powerful enough to confirm if our universe was a Gödel universe. As the technology became more sophisticated throughout his life up until his death in 1978, Gödel would ask, "Is the universe rotating yet?" The answer was always no. As best as we can tell, our universe is not a giant CTC, but Gödel might not be out of luck just yet.



A Gödel universe represented by “light cones” and
a possible path of a light through spacetime.

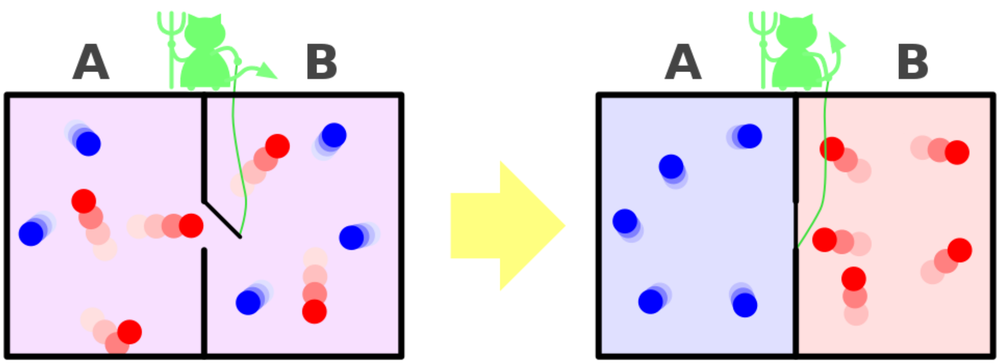
Reverse causation, as Hanley defines it, is simply “a cause and effect relation where effect precedes cause.” Any notion of reverse causation, or causal loops in general, is intimately tied to information. Every single event or state of the universe exists in terms of information, as does each causal relationship. Information is also what makes events distinct and unique. If the universe were to suddenly return to some state *X* that existed an hour ago -- informationally identical in every way -- then we’re not talking about another state similar to *X*; that *is X*. Each event in a causal loop is fully and uniquely described by information.

One feature of our universe is that information becomes increasingly diffuse, a natural result of the second law of thermodynamics, which holds that the universe always trends toward maximum entropy, or equilibrium. Entropy can be understood as a measure of disorder; it always tends to increase locally, but the overall entropy of the universe stays constant. Said another way: although information is never actually lost, it tends to become more disordered.

Therein lies our grand dilemma. As physicist Lee Smolin writes in *The Singular Universe*, “The fact to be explained is why the universe, even 13.8 billion years after the Big Bang, has not reached equilibrium, which is by definition the most probable state, and it hardly suffices to explain this by asserting that the universe started in an even less probable state than the present one.” How did the universe ever arrive at a more ordered state when it clearly prefers the opposite? Obviously it's a conundrum in our existing models, but doubly so if we are to imagine a future in our causal loop that goes totally against a law of nature. This question has already drawn some eyebrow-raising proposals.

Ludwig Boltzmann, the 19th century physicist who *developed* the second law of thermodynamics, gave one proposal: the second law is a statistical phenomenon, so given enough time, there's a non-zero chance the universe will randomly fluctuate back into a highly-ordered state. But according to Boltzmann's own principles, something like the big bang is literally the least likely thing that can happen; while not necessarily impossible, we're going to explore a more probable scenario.

A contemporary of Boltzmann, James Clerk Maxwell, devised a thought experiment called "Maxwell's demon" in an attempt to violate the second law. He imagined a demon that controlled a small door between two gas chambers. As individual gas molecules approached the door, the demon would quickly open and close it so that all the fast molecules became trapped in one chamber, and the slow molecules in the other. In doing so, Maxwell proposed the second law was violated since the chamber system became more ordered; one side became hotter and the other became cooler, even though it was totally mixed before. With regard to information, entropy had been lowered -- or so he thought.



In this Maxwell's demon setup, chambers A and B both start with mixed gas, but over time chamber A becomes cold and chamber B becomes hot. (Source: Htkym / CC BY-SA)

Others said not so fast. Although entropy in the chambers decreased, the entropy in the demon's *memory* increased. Imagine that the demon's memory started as a blank slate -- highly ordered. As it observed the system, it had to fill its memory with information about the gas molecules to know how to operate the door. In doing so, the information in its memory became more disordered, thereby preserving the second law.

But the demon can just forget that information, right? In doing so, its memory goes back to a blank slate, but the gas is still highly ordered. Seems like an easy solution. Again, not so fast -- the loss of information entails a dissipation of heat, which increases the entropy of its surroundings. Alas, it seems the second law cannot be slayed. But maybe it doesn't need to be.

When looking at the entire system in Maxwell's thought experiment -- which really includes the chambers, the demon, and the demon's environment -- we notice several things. One is that information can take several forms, such as the properties of gas, memory in the brain, and in the effects of heat. Another is that although the second law is maintained and entropy's trend toward disorder never ceases, local arrangements of information can become more ordered, thus local entropy can decrease. To reiterate an earlier point: overall entropy never changes, but local entropy can. A third observation concerns what is required to produce local order: the demon. More generally, knowledge about the system, or memory, as well as the ability to act upon it to rearrange information. In fact, if an agent has perfect knowledge of a system, it can rearrange it in any way it desires.

Maybe you can see where this is going -- intelligence can manipulate information, and enough intelligence can hypothetically recreate a prior state of information in its own system, maintaining a causal loop.

Let's recap a bit: if we assume our universe is a causal loop, but it is not a CTC, and it probably did not randomly fluctuate to a highly-ordered state, then the only option left is to think that intelligence was used to cause a previous, highly-ordered state in the loop.

You may think "yeah, but what are the odds of that?" I'm inclined to respond with, "better than the alternatives." Remember, Hanley tells us these things are not impossible, they are merely coincidental; *and* causal loops are more likely to happen in a universe with intelligent agents. If a causal loop is the only type of universe that can exist, then it's not coincidental at all; it's simply how anything must exist. That alone eliminates the apparent absurdity. And although we're working with a sample size of one, the fact that our universe hosts intelligent life already makes the "intentional causality" path more probable than a random fluctuation.

I'll also add that this aligns with my discussion on quantum annealing, where a quantum annealing universe converges on it's highest probability state. If the many parallel timelines in the MWI follow a probability distribution, and all timelines must form causal loops, then not only are the most probable loops are those that contain intelligence, as Hanley suggests, but each loop that takes the intelligence "route" must ultimately land on a set of common characteristics -- they must all have the ability to manipulate information, or reality itself, in order to maintain a causal loop. If any one of them did not converge on this knowledge or technological sophistication, then the timeline would not exist in the first place, thus would not be included in the probability distribution. As such, any timeline *we* follow in the causal-loop-MWI formulation must converge on those traits too.

I also explained how a reward function within quantum annealing would result in the system having incentive to "restart" itself in order to maximize reward. Both causal loops and a quantum annealing universe involve a convergence on intelligence to facilitate a restart, and they involve the act of "forgetting" in order to restore a previous informational state. And although it's far cry from any firm proof, this heat-releasing forgetting process sounds a lot like our early universe -- a hot universe with a highly-ordered state.

From my perspective, causal loops and quantum annealing look like two sides of the same coin. Is it a coincidence that we seem to arrive at the same conclusions from two entirely different approaches? Or have we done away with coincidences?

MAKE IT LOOP: A HOW-TO GUIDE

We manipulate information every day, whether it be physically, mentally, or digitally, but we could use more guidance in the way of resetting a universe -- it's a tall order. Information and entropy can take many forms, but there does appear to be one form that rules them all: Von Neumann entropy. I couldn't possibly summarize it better than physicist Matt O'Dowd from *PBS Space Time*, so I won't try:

> Quantum entropy, also known as Von Neumann entropy . . . describes the hidden information in quantum systems, but more accurately, it's a measure of entanglement within quantum systems. In fact, the evolution of quantum entanglement may be the ultimate source of entropy, the second law, the limits of information processing, and even the arrow of time.

Von Neumann entropy is of particular interest in the study of quantum information -- namely, in black holes and quantum computing. One foundational tenet of quantum theory is that quantum information is never lost or destroyed. This presented a real problem in the "black hole information paradox" where physicist Steven Hawking pointed out that information seemed to be forever lost through what he called Hawking radiation, where information-carrying particles fall into a black hole, adding to its mass, but this same mass can escape through informationless photons, thereby erasing information.

Many physicists thought this paradox couldn't possibly be, so they devised several solutions to resolve it. Hawking himself even abandoned the paradox, convinced that information was preserved. One promising solution uses entanglement, the phenomenon whereby two particles, or qubits, must be described as a single state. In this solution, the photons escaping through a black hole's radiation are imprinted with information through entanglement -- information that can theoretically be retrieved. Norman Yao, from the University of California, Berkeley, told *Quanta Magazine*, "If you were God and you collected all these Hawking photons, there is in principle some ungodly calculation you can do to re-extract the information in [each swallowed] qubit."

Is a literal God required to gather the information needed to connect our loop? Maybe, but I'm only human, so it's beyond me. Perhaps it's not the only option though. What if we don't need to know everything; we just need to know *enough*? As intelligent beings, we do have the ability to reason after all. Can we arrive at the necessary information by means of deduction, without having all the raw data? A step in that direction might concern entanglement; it doesn't just save information from being lost in our universe -- it might show us how to reconstruct our universe.

One implication of the entanglement solution to the black hole paradox is that our universe may be a hologram. It sounds rather strange, but the "holographic principle" is taken quite seriously and is of great interest in the quest for quantum gravity. In this approach, spacetime emerges from a network of entangled particles, and our entire universe may be a hologram of information encoded on the surface of a black hole. This is where we may be able to make some progress.

As I mentioned, Von Neumann entropy is also relevant to quantum computing. In fact, there are remarkable parallels between black holes and quantum computing, and the more we study one, the more we tend to learn about the other. Advancements in quantum computers allow us to probe the mysteries of our universe. We've already been able to do some pretty mind-bending things with experimental systems, like those that mysteriously "snap back" into order from equilibrium, entangle particles over time (not just space), reverse time, and challenge our notion of normal causal order. In time, we may come to find that we actually live in a quantum computer; which means -- in keeping with a causal loop -- we'll recreate the universe through quantum computing too.

It's no secret I'm a strong proponent of one particular form of quantum computing as a model of our universe: quantum annealing. In alignment with the holographic principle, quantum annealing utilizes a network of entangled qubits, where entanglement steadily increases in accordance with our observations of Von Neumann entropy. There are many other similarities (and I promise I'll stop mentioning quantum annealing now), but my point, more generally, is that there are reasons to believe we can indeed recreate the universe through some form of quantum computing. For simplicity, I'll discuss this in terms of a "simulation," but I want to emphasize that this doesn't imply a simulation is any less "real" than anything else -- it's all quantum information at the end of the day, and existence within a causal loop could just be simulation in perpetuity anyway.

From my vantage, this could go one of two ways. In each scenario, the goal is to create a matching "first" moment within a simulation; as long as that configuration of information is always the same between simulations, and a nested simulation remains coherent, then the causal loop is maintained. Again, an event on the loop is simply a specific arrangement of information. Both options require a super-advanced civilization in our distant future; relatively speaking, they may even seem like gods, but these options don't require capital-G God.

The first way is that we're able to deduce some set of parameters and initial conditions of our universe. If we exactly calculate its information capacity (Beckenstein bound), universal constants, laws, and find a grand unified theory, then we can also find some entanglement geometry that permits all of those properties. We'd then create a quantum system with matching parameters and hope we run it from the same “starting” point as our own -- that might be some point of minimum entropy where the system couldn’t possibly be any simpler, similar to how we view the singularity before the big bang. This assumes that some simulation “before” us chose the same starting point as the obvious choice since any possible timeline can then follow as its trends back towards equilibrium. The enormous energy required for such a task might spell the annihilation of the parent simulation, like a cosmic self-sacrifice, but maybe that’s the point.

The second and possibly more intriguing way is the “message in a bottle” approach. Imagine that when a simulated universe is programmed, instructions are left for the inhabitants of that simulation to then recreate the same simulation. This makes sense if intelligent life has a vested interest in maintaining the causal loop it occupies. They would leave instructions in something ubiquitous and unchanging like the universal constants, the cosmic microwave background, or in our DNA. In fact, all human DNA differs by less than 1%, and about 98% of our DNA is considered to be non-coding, or “junk” DNA -- it’s an ingenious place to pass along crucial information. And DNA is simply a pattern of information that can be easily programmed; meaning DNA would be encoded into the initial conditions, so the universe emerges *around* DNA-based life, differing from the “absolute simplicity” initial conditions of the first option. Though, we’d still require a universal language that can be understood by any intelligent life to decode the instructions; maybe it all really is in the maths and options 1 and 2 are more alike than we think.

It’s also worth noting that Hanley specifically cites the use of genetics in an example of a “person loop,” where, “Given the normal recycling of cells, it may be that a person’s body has entirely replaceable parts.” Yet genetic code (ideally) remains unchanged, so that information could remain consistent in a loop. In fact, if DNA is the focal point of a causal loop, then it seems the only information that needs to be simulated is that which constitutes the experience and collective memory of DNA-based life. If information changes outside of that, who would ever notice? The information requirement for this simulation becomes much more manageable since we don’t need to render every property of every particle throughout the observable universe.

Of course, this is all wild speculation, but it does make for a fun exercise. Maybe there are alternative routes that will become obvious as we learn more about reality. I’m just trying to get the ball rolling in case we do live within a causal loop. It's my loop too, after all.

FINDING GOD

When exploring the idea of a causal-loop-only universe, it's almost impossible to ignore some of the implications for life within that universe.

For one, it appears to make intelligent life necessary for *anything* to exist -- at least in any universe that’s not a CTC. From this view, life isn’t rare: it's required. If no intelligence emerges, there is no feasible way for a causal loop to remain informationally consistent. This also means that any life-carrying universe must follow a series of causes and effects that enable a minimum degree of intelligence and agency -- life must gain the ability to manipulate the information of the universe itself. So not only is intelligence required, but *highly advanced* intelligence is required.

What does this all look like from the perspective of life within such a universe? Well, look at our own -- the entire universe is “cooling down” towards disorder, but intelligent life and what it touches are the only things that trend towards more order. Over time, our knowledge and technological capabilities increase. What’s the upper limit to this trend? Is it a coincidence that we’ve come to a point where we can start exploring and controlling quantum information, the very fabric of reality? How much more will we achieve in the next century, millennium, or ten millennia?

Maybe we really have just gotten lucky, but in a causal loop this trajectory is not a coincidence -- it's a certainty. Life doesn’t just veer off the rails into oblivion; it’s locked on a path, or lots of equivalent paths that are all destined to tell the same story -- the same universal archetype. The loop cannot be broken, else it would have never existed. Life is bound to persist, bound to overcome, bound to exist again -- isn’t this the kind of hope people normally place in God?

I’m not saying God literally exists. *Maybe* an omniscient being exists as the highest expression of intelligence on a loop right before it must reset, but that seems like a distraction to a more meaningful point: existing in a causal loop -- at any point -- is *practically* like living in a universe where God exists too.

Isn’t that the case if nearly everything about existence takes the shape of a series of unending coincidences? Otherwise, the odds of life arising in our universe are astronomically unfavorable, as is the fact that life has evaded extinction for a few billion years to become what it is today. If you recognize coincidence after coincidence, it's not much of a leap for a rational mind to think that a higher power ordains each moment, following some grand design. Many of us have stepped away from that worldview, but maybe we just had an incomplete perspective. Maybe we have reason to believe again. As we step closer to truth, we might see that our old silhouette of God was simply the shadow of an equally hopeful structure of reality.