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Life, but Not as We Know It: Why Fine-Tuning Arguments Fail

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ABSTRACT

Definitions of "life" and theories of life are systematically neglected in arguments for and from fine-tuning. Despite claims to be neutral about the definition of "life," fine-tuning arguments generally presuppose that life requires a form of structural complexity only afforded by physicochemical complexity of the sort with which we are familiar, and more specifically, by water and carbon molecules. Conversely, our best accounts of life construe life as a matter of *dynamic* rather than structural complexity, and as substrate- and scale-independent. Life could be as radically different in the possible universes considered as their physics is. We have no idea whether the relevant form of dynamic complexity would develop in possible universes radically physically unlike our own.

1 | Introduction

We have no idea whether the universe is "fine-tuned" for life. We have no idea what range of possible universes, however the space of possible universes is to be specified, might support life. The existence of life should not be the basis for inferring either that the universe has an intelligent and life-friendly designer, or that there is a multiverse.

There is a large body of literature on the "fine-tuning argument," dating back at least to the 1950s, a popular topic of discussion in cosmology. Fine-tuning arguments, based on the premise that the universe in which we live is particularly amenable to life compared with other possible universes, have been used to support several different conclusions, most notably that the universe was designed to support life and that there is a multiverse.

In this literature, a frequently expressed and almost-as-frequently dismissed worry is that there is no operative definition of "life." The concern is that we cannot judge the likelihood of life in radically physically different universes without such a definition, because without such a definition, we cannot specify the range of possible forms of life. Fine-tuning arguments often start with the claim that life as we know it could not have existed in other possible universes. If the correct definition of life is sufficiently expansive, this might be true but uninteresting: perhaps life is as it is because of the physical constants of our universe, but different physical constraints would have given rise to different forms of life.

Many forms of the fine-tuning argument attempt to circumvent such worries. It is far from clear that they succeed. They aspire to offer arguments for fine-tuning which are insensitive to different possible definitions of life. Without a definition of life, it is hard to move away from defining life at least somewhat *ostensively*: by pointing to life as we know it, and asking whether there are things *like that* on distant planets or in possible universes unlike our own. It is therefore surprising that our best scientific definitions of life are entirely absent from these debates. There are influential definitions of life on offer, which they do not consider.

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Discussions of fine-tuning have engaged heavily with physics, mathematics, normative models of statistical reasoning, and biochemistry. They have not engaged with our best recent theoretical frameworks in biology and cognitive science that promise to define life. "Best" does not imply perfect. There are plenty of reasons that one might be skeptical of such definitions. Even so, this lack of engagement is surprising, since such definitions seem to provide at least some promise of escaping the trap of defining life by ostension—by pointing to life as we know it.

The currently dominant definition of life has several features, which are amenable to the kind of skeptical position about fine-tuning that I am offering here. It is substrate-independent and scale-independent. The kind of complexity required is behavioral and dynamic, but not structural. By contrast, the focus on carbon-based life in fine-tuning arguments appears to be based on an emphasis on *structural* complexity, and charitably perhaps also the assumption that this kind of complexity is required for behavioral and dynamic complexity.

2 | Defining "Life"

The "free energy principle" in biology and cognitive science offers a mathematically complex but conceptually simple definition of life: a living system is one that is actively self-sustaining (Friston 2013). I will try not to fall into formalism here; for an overview, see Mann et al. (2022). The main disputes surrounding this definition focus on the mathematical formalism.

The formal, mathematical framework of the free-energy principle characterizes self-sustaining systems in terms of systems that minimize the conditional dependence of the state of their inner milieu on the world beyond their boundaries. These boundaries are statistically defined in terms of a "Markov blanket," defined in terms of this conditional (in)dependence. So, for example, the boundary of a bacterium is the boundary at which changes beyond that boundary become markedly less likely to cause a change within that boundary. A bacterium is a living system because it actively maintains this boundary, that is, because it is an actively homeostatic system which aims to maintain stable internal conditions in the face of environmental perturbations.

The formalism becomes significantly more complex because organisms are not merely homeostatic. They carry out *allostasis* as well as *homeostasis*: that is, they aim to maintain their long-term inner stability by two distinct means. First, they maintain their long-term internal stability by *homeostasis*, that is, keeping specified internal parameters within a stable range. Second, they maintain their long-term internal stability by *allostasis*, that is, by *changing* the state of their internal milieu to pre-empt environmental changes. For example, in humans, blood pressure is increased in the face of serious threats in order to create a state of action-readiness that might in turn reduce the possibility of a fatal change to one's internal milieu: for example, one's insides being eaten by a lion.

The formalism itself is subject to significant skepticism. It appears to apply trivially to nonliving systems and to have no tools to specify the difference between actively self-sustaining and merely stable systems (Nave 2025). Its status as a scientific model is argued to be dubious by some (Andrews 2021)—it is instead perhaps an interesting tautology, conceptual framework, or hypothesis-recipe analogous to evolutionary theory (Sims 2016, 2017). There are more specific formal problems with the theory, especially with its extensions to allostasis (Millidge et al. 2021). However, even among those who reject the formalism, the idea that life is constituted by systems which are actively self-sustaining in sufficiently complex ways is widespread (Godfrey-Smith 1996; Nave 2025; Varela 1979; Wever and Varela 2002).

There are several features of this definition of life which seem likely to survive into any successor theory, since they are independent of these problems with the formalism and shared across many of the competing accounts. The first is that it is both substrate- and scale-independent. For a system to be alive, it must engage in sufficiently complex *activities* geared toward self-maintenance. It makes no specifications about the time-scale of these activities, nor about the spatial scale on which these activities take place. Indeed, within life as we know it, there are significant variations in both time-scale and spatial scale: a giant redwood is just as alive as a bacterium, which is just as alive as a human. But the activities of these systems take place on temporal and spatial scales which differ by orders of magnitude. It also makes no demands on the substrate. That is not to say that, in the actual world, there are many substrates which can in fact instantiate sufficiently complex self-sustaining activities (cf. Polger and Shapiro 2016). But in the context of the fine-tuning argument, where the goal is to consider radically different sets of physical laws, there is no *prima facie* reason to believe that only structurally complex carbon-based systems can implement these activities as a matter of cross-world *necessity*.

It is important to stress the distinction between *structural* and *dynamic* complexity. Complexity is a broad concept, widely used across the sciences. Many characterizations emphasize *structural* features of systems claimed to be complex, broadly understood in terms of the "number and differentiation of parts and irregularity of their arrangement," often also involving notions such as hierarchical organization (Taborsky 2014: 48). Many other characterizations emphasize *dynamic* features of systems claimed to be complex, "generative, dynamic, and regulatory notions, such as self-organization, emergence, adaptation, and feedback" (Taborsky 2014: 48). These two kinds of features are often related: the former often enables the latter. I will treat these as two legitimate notions of complexity: dynamic complexity, which bears on the behaviors of a system and its internal dynamics, and structural complexity, which bears on the physical parts of systems, their features, and their organization. The dominant kind of characterization of life requires *dynamic* complexity. Structural complexity is *only* required by this kind of characterization to the extent that the dynamic complexity of the right form requires structural complexity to implement it.

3 | Dreary Universes

The fine-tuning argument often requires the premise that only some narrow range of possible universes would have the right kind of conditions for life to develop. The wide range of possible universes, it is claimed, circumvents worries about the definition of life. Often, the fine-tuning argument asserts that most possible universes fall into one of two life-hostile categories: "super-dense" universes, where matter is highly condensed and the big bang never really gets off the ground; and "super-sparse" universes, where the big bang is too big and no molecules form. Both kinds of universe rule out physicochemical complexity of the sort with which we are familiar; they are universes without stars, without carbon, without water, and indeed without any molecules to speak of. Our universe exists in a "temperate zone," where the big bang was just big enough for physicochemical complexity to arise, and hence for life to arise, so they claim.[1]

In view of this, they see definitions of life as unimportant. Manson claims that if any of the fundamental physical parameters—the mass of the proton, or of the neutron, the speed of light, and the gravitational constant—differed outside of a very narrow range, "the universe would not have been the sort of place in which life could emerge—not just the very form of life we observe here on Earth, but any conceivable form of life" (2009: 272). In a book praised for being indicative of the state of the current literature in cosmology (Benétreau-Dupin 2017), Lewis and Barnes assert that the range of possible universes "makes worries about the different definitions of life into a mere technicality" (2016: 266; see also 266–274).

Several more recent authors pay little or no heed to the possible range of forms of life. Dorst and Dorst (2022) and Saad (2024) take it for granted that only a narrow range of possible universes could support life. Barnes (2019: 1220) simply asserts that "an extraordinarily small subset would have resulted in a universe able to support the complexity required by life."

None of these authors considers any of the definitions of life on offer in the life sciences. Those authors who talk at all about the nature and requirements of life clearly assume that life must be significantly as we know it. Lewis and Barnes ask, "if life is so easy, why does life as we know it rely on such extraordinarily complicated organic chemistry?" (2016: 267), and early on operationalizing the existence of life in terms of the possibility of physicochemical systems of at least similar (structural) complexity to cells as we know them (2016: 11). Manson, despite claiming to be arguing about "any conceivable form of life," baldly asserts in parentheses that "carbon is essential to life" (2009: 272), and later that stars are also essential to the development of life (2009: 274). Even Adams's (2019) sophisticated criticism of the fine-tuning argument, which demands greater engagement with biology and considers the possibility of, e.g., silicon-based life, still fails to consider the relevant definitions of "life" and treats carbon- and silicon-based life as exhaustive of the possibility space without argument.

4 | Life in a Dreary Universe

In relation to the characterization of life dominant in the life sciences and discussed in Section 2, it is far from clear that there can be no life in a dreary universe. What is needed, and what is absent from arguments for and from fine-tuning, is an argument that the kind of *dynamic* complexity required by life relies on the kind of *structural* complexity afforded by physicochemical complexity in general (and water, carbon, and stars in particular), *not only* in our universe with its actual physics *but also* in universes with radically different physics. No such argument has been offered.

My claim here is not that we know that there *can* be life in dreary universes, super-dense or super-sparse, but that *we have no idea*. That is, we have no idea whether there could be systems that engage in sufficiently complex forms of self-maintenance in a big super-dense ball of matter, nor whether there could be such systems in a sparse and scattered cosmos. More specifically, my claim is that there is no good reason to think that there could or would not be life, as characterized above, in the ostensibly dreary universes.

Nothing in the nature of life, according to our best theories of life, rules it out. The substrate-independence of life obviously matters here: the basic ingredients of life as we know it would not exist in many possible universes, so it is important that life is not substrate-dependent or life would be precluded in dreary universes. The scale-independence of life also matters here. For example, even granting that in a super-sparse universe life could not exist at a spatial or temporal scale anywhere near as small as our own, this does not preclude much larger and slower systems which are actively self-sustaining from existing in a super-sparse cosmos. Super-dense universes might preclude life at a scale as expansive as our own, but would not preclude quick and tiny self-sustaining systems from existing.

The question, then, turns on whether sufficient dynamic complexity is possible in super-dense or super-sparse universes. What the fine-tuning argument requires, if it is to get off the ground, is an argument that the relevant sort of dynamic complexity is not possible in most possible universes. The most promising way, it seems to me, to make such an argument is to argue that the relevant sort of dynamic complexity requires sufficient structural complexity, and that such structural complexity in turn requires the kind of physicochemical complexity which is present in our universe but absent in most possible universes.

Charitably construed, the authors discussed above perhaps do offer such an argument in schematic. In the actual world, every form of life known to us is highly structurally complex, and this structural complexity relies on the physicochemical complexity afforded by carbon-based molecules and water (as well as on the sun for its development and for the presence of these molecules). Since this is true of every instance of life with which we are familiar, we should expect it to be true of life in general. Thus, we should at least see it as more likely that life is absent in the dreary universes than that it is present, as they might claim.

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[1] Barnes (2019) takes a slightly different tack. Instead of arguing that we exist within a "temperate zone," a narrow range of possible universes where life might develop in a spectrum of possible universes mostly hostile to life, he argues that *nearby* possible universes would be hostile to life—that even small changes to physical constants would result in dreary universes of the sort discussed in the next section. As such, he argues *not* that we find ourselves in a temperate zone within a broadly hostile spectrum of possible universes, but instead that we find ourselves in a life-supporting universe which falls within a particularly hostile range of possible universes, relying on no claims about the broader spectrum of possible universes. This does not affect my arguments about the perceived dreariness of the pertinent possible universes other than our own, since the arguments that these universes (whether modally distant or modally close) would not support life remain the same, and face the same problems.

Even setting aside the more speculative possibility that there may be forms of life in our universe which we do not and perhaps cannot recognize because of their radically different substrates and scales, this inference is deeply unsafe, and the argument above does not hold. We do not have a good reason to believe that the relevant sort of dynamic complexity requires sufficient structural complexity. We also do not have a good reason to believe that that kind of structural complexity can be realized only by the kind of physicochemical complexity with which we are familiar.

First, in the actual world, we know that dynamic complexity and structural complexity can come apart. Flocking birds, for example, the murmurations of starlings involve highly complex group-level behaviors with very little structural complexity: the birds follow extremely simple rules as part of their flocking behavior, but the dynamics that emerge as a result are highly complex. Dennett (1991) illustrates this point at length with Conway's game of life: structurally simple systems, comprising simple, homogenous parts each governed by simple, evenly applied rules, can exhibit a high degree of dynamic complexity. In both of these extremely simple toy examples, these complex dynamics include rudimentary forms of self-maintenance.

Moving beyond the actual world, an obvious point is that the possible universes we are considering are very different than our own. Even if the relevant form of dynamic complexity required high levels of structural complexity in the actual world, we would have no good reason to believe that this is true in these radically different possible universes.

One might balk at this claim. One might think that we can use our established physical and chemical models, adjust the parameters a little, and establish to a reasonable degree of accuracy and certainty how matter would behave in these radically different universes. The trouble with this claim is that it relies on an untenable picture of the nature of knowledge and modeling in physics and chemistry.

Models rely on application conditions for their usability in science—controlling for background factors and potentially intervening variables, and generally ensuring that the circumstances to which the model is newly applied are sufficiently similar to the circumstances in which it was established to work. Accepting this claim does not require a descent into mere instrumentalism about models and physical knowledge. For example, Cartwright (1983, 1999) argues at length that physical models establish real capacities of real entities, but that they can only establish capacities that manifest under certain conditions, and only that they manifest under the tested conditions and conditions that are sufficiently saliently similar.

Think, for example, of the Large Hadron Collider. To gain further knowledge about fundamental physical particles, it has been necessary to create an incredibly controlled environment that exposes microphysical entities to conditions to which they have not been exposed since the beginning of the universe. The results are often surprising: we do not generally know ahead of time exactly how the relevant entities will behave under these new conditions. They are also limited in their scope: if the Large Hadron Collider were more porous, if the possible interference and intrusion of other material entities were not precluded, it is unlikely that the tested particles would behave the same way.

Because of these features of physical and chemical models and knowledge, matter regularly behaves in ways that we do not expect in radically different conditions than those with which we are familiar. For example, Bursten discusses the properties and behavior of gold. In a vacuum, isolated, without interaction, a gold atom is simply an atom with "79 protons, 79 neutrons and electrons, some electronic symmetries and characteristic dispositions toward bonding, but without any macroscopic properties whatsoever—no color, no temperature, no malleability or ductility" (2018: 2). As we know from the long experience of human history, heating it up sufficiently under atmospheric conditions creates a molten puddle which is great for metalwork; when it cools again, its electrons are delocalized, it is chemically inert, and it looks "yellow and shiny" (2018: 1). But under still-different conditions, it has radically different properties again, properties that our models would not have enabled us to deduce ahead of time:

> if I rearrange the atoms in my lump into clusters of a few hundred atoms each, all these properties change. In order to preserve this new arrangement of atoms, the clusters will need to be suspended in a carefully-prepared solution that has been designed to fight the forces of surface tension, chemical kinetics, and thermodynamics so that the clusters will not coagulate back into one massive lump. The individual clusters in this solution have physical properties, such as conductivity and ductility, that differ from the physical properties of the lump and which change depending on the size, shape, and surface chemistry of the clusters. Collectively, the clusters appear differently-colored than the shiny, yellow lump: out of solution the group of clusters has the dull, reddish-black appearance of river mud; in solution, the clusters turn a previously-clear liquid red or brown, a color brought about not by normal pigmentation but instead by a rare optical phenomenon known as localized surface plasmon resonance (LSPR). This phenomenon only occurs when the clusters are small enough that their diameter is shorter than the wavelength of visible light. And finally, in contrast to the big lump of gold, these clusters are catalytically active—that is, they can be used to speed up other reactions that are performed in solution with them. (p. 1)

That is, when we create (at great effort) extremely unusual conditions for gold, it exhibits properties radically different from those it exhibits in other conditions. Some of these—for example, its catalytic role—are extremely significant to its behavior under such conditions. They also affect the behavior and properties of the materials *around it* in significant and hard-to-foresee ways. If we take *two* materials and put them in radically different conditions, the complexity of predicting their behavior radically increases: not only might the properties they exhibit individually change, they may also affect the properties exhibited by each other.

In considering other possible universes, we are asked to take *all the material in the universe* and put it into radically different conditions—conditions more radically different than a suspension of gold or the Large Hadron Collider—with *no* interference or intrusion controlled for. Our knowledge of how materials would behave in a super-dense or super-sparse universe is extraordinarily limited. We thus have very little basis for inferences about the dynamic complexity of which structurally simple systems would be capable.

We have equally little basis for judging the *structural* complexity of systems that might be possible under such conditions. In our universe, physicochemical complexity is achieved largely by a variety of kinds of chemical bonds. In a universe where all matter existed in one super-dense lump, or in a universe where it was all spread out over huge spatial scales, we have very few tools for thinking about what other forms of structural stability and composition might arise or be possible.

The fine-tuning argument owes us some reason to believe in its key premise: that life would not exist in universes radically physically different from our own. Given the dominant characterization of life, this requires an argument that those universes would not exhibit the right kind of dynamic complexity. Gestures toward the importance of carbon and water in our universe do not suffice. We simply have no idea whether these radically different universes would be able to exhibit the right kind of dynamic complexity to contain sufficiently sophisticated, actively self-sustaining systems.

There is an objection worth briefly considering here. One might interpret my argument as counting in favor of the view that many possible universes other than our own contain life. One might nevertheless believe that *most* possible universes other than our own contain none, and hence that the fine-tuning argument still provides some reason to believe in the multiverse or in design. Perhaps my argument shows that if there were no multiverse or design, it would be *less* surprising that life exists in our universe, but it fails to show that it would not be *at all* surprising. If this were the right interpretation of my argument, it would mean that the existence of life in our universe provides *less* support to the multiverse and to design, but still *some* support. However, that is not the main thrust of my argument.

My argument here is not a positive argument for believing in life in universes other than our own, neither all other possible universes nor merely some other possible universes. Rather, it is an argument that we have no idea how widespread life might be across possible universes. Previous arguments for the *absence of* life in other possible universes—whether all of them, most of them, or those nearby in possibility space—fail. They fail because they have not engaged with the dominant view of life as a matter of dynamic complexity, and have relied on the untenable assumption that life requires physicochemical complexity of the sort relied on by life as we know it. My argument is not even an argument that we *cannot*, in principle, work out how widespread life is across possible universes. Instead, it is an argument that we *have not* worked this out, because of a central lacuna in discussions of fine-tuning: the nature of life, the very thing whose distribution across possible universes is at issue.

5 | Objection: What About Cognition?

One might object to the preceding that the concern of those offering fine-tuning arguments was never really life per se, but life as a proxy for observers like us. *We* exist, as well as trees and bacteria, and we, unlike them, can contemplate the fact that we exist, observe the universe, formulate physical theories, including in ways that allow us to specify physically different possible universes, and so on. Perhaps, one might wonder, it is observers with cognitive capacities like our own that get the fine-tuning argument off the ground.

One advantage of the free-energy principle in this debate is that it is as much a theory of cognition as it is a theory of life. Many proponents of the free-energy principle characterize cognition in much the same terms as they characterize life. Life requires active self-maintenance, including both homeostatic and allostatic activities (Pezzulo et al. 2015). A particularly advanced form of allostatic activities involves being in some (to-be-discussed) way sensitive to *counterfactuals*: to disturbances to one's inner stability that *would* arise, *were* certain events to transpire. This kind of counterfactual sensitivity, in turn, is claimed to give rise to certain kinds of inquisitiveness and exploration: it motivates systems to undertake "epistemic actions" that help to identify and rule out merely possible risks, and to go about building an increasingly complete model of the world which can guide their behavior (Friston et al. 2012; Pezzulo et al. 2015). The free-energy principle is closely tied to a theory of the *implementation* of this kind of cognition in human nervous systems, known as "predictive processing," which operates within a Bayesian framework (Clark 2016), and in particular to the "active inference" version of that theory.

For many proponents of the free-energy principle, cognition is just a more sophisticated version of the same kind of dynamic complexity as life (Sims and Kiverstein 2021). Again, this view transcends the limits of the free-energy principle. Many of those who are not proponents of the free-energy principle and its mathematical framework, but believe that life consists of actively self-sustaining systems, believe that cognition operates on principles continuous with those of life (Godfrey-Smith 1996; Thompson 2007; Varela et al. 2016).

However, this is not a universally held opinion. Some proponents of the free-energy principle offer a view of cognition such that it arguably does entail a certain kind of structural complexity. The difference lies in what the above-mentioned counterfactual sensitivity requires. If it is merely dynamically sensitive (reliably acting in ways that minimize counterfactual risks), cognition is clearly just as much a dynamic phenomenon as life (Sims and Kiverstein 2021). However, if this sensitivity must consist of *explicit representation* of these counterfactual risks (Corcoran et al. 2020), then it may impose some structural constraints on which systems count as cognitive.

If genuine cognition requires explicit representations, which are sufficiently decoupled from their environments and can be processed as part of abstract reasoning (Clark and Toribio 1994), then it plausibly imposes a requirement for a certain level of structural complexity on cognitive systems. Cognitive systems must instantiate tokens of types, where these tokens have causal "syntactic" properties which in some sense mirror their "semantic" properties, and where semantically meaningful state transitions in reasoning processes are reliably associated with the causal properties shared among tokens of a given type-representation (Davies 1998; Fodor 1975).

I do not wish to endorse or argue for either of these views—that cognition requires explicit representation, and that explicit representation requires a certain level of structural complexity. Nor do I wish to reject them. If either of these views is false, then cognition is no more troublesome than life for my argument: we have no more idea about whether there can be cognitive systems in radically physically different universes than about whether there can be living ones.

If both of these views are true, things are a little more difficult for my argument. However, there are three points to note. First, proponents of fine-tuning have not offered any reason to believe that life *or cognition* thus understood cannot be instantiated radically, aside from references to the significance of water, carbon, and stars in *our* universe. Such an argument is owed if explicit discussions of life were treating it as a proxy for cognition.

Second, explicit representations, even thus understood, are not particularly costly in terms of structural complexity. Electrical impulses, vectors in high-dimensional state spaces defined in terms of non-hierarchically organized and undifferentiated components, simple physical tokens in simple Turing machines, and much else besides are able to meet the requirements on structural complexity and qualify as explicit representations. Third and finally, in light of our lack of knowledge of what forms of structure might be possible in a radically physically different universe, we have no idea whether these relatively undemanding forms of structural complexity might be possible in such universes.

It is worth flagging that there have been arguments against the *multiple realizability* of cognition (Polger and Shapiro 2016). These arguments do not deny that cognition can be characterized in dynamic, substrate-independent, and scale-independent terms—and it is in these terms, rather than in terms of multiple realizability, that I have been approaching the question. These arguments deny that in the actual world, cognition can in fact be realized in multiple ways, highlighting coarse-grained physical similarities between the systems that instantiate cognitive capacities and states. In the context of actual-world science, based on and limited to the actual world, they claim that this suffices to show that our best science should not view these states as multiply realizable. However, in the context of fine-tuning, we are explicitly setting out to consider universes that are radically physically different. These arguments are therefore not relevant to the discussion here.

6 | Conclusion

Life is, according to our best theories in the life sciences, a matter of dynamic complexity, as well as scale- and substrate-independent. Cognition may well share these features. If not, that is, if cognition requires explicit representation and if representation requires a certain level of structural complexity, it is nevertheless scale- and substrate-independent, as well as imposing only very minimal structural constraints. We have, for principled reasons to do with the status of models and epistemological practice of the physical and chemical sciences, no grip on what kinds of dynamic complexity might be possible in universes radically physically different from our own, and insufficient grip on what kinds of structural complexity might be possible to rule out simple structural requirements being met. Appeals to the way life as we know it works and develops—to carbon, water, and stars—hold no weight. As such, we have no safe basis for making inferences about the possibility of life and cognition in radically physically different universes: we simply have no idea whether our own universe is fine-tuned for life or cognition.

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