The Anthropic Principle and Multiple Universe Hypotheses

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Abstract

The universe appears to be fine-tuned for human life, which leads some to conclude that the universe must have been created for us. The Anthropic Principle is an attempt to dispel that argument, by stating that humans could only exist in a fine-tuned world and thus that it is not surprising that our world is (and seems to be) fine-tuned. I argue that to dispel the most surprising fine-tuning coincidences–those regarding the physical makeup of the universe–the Anthropic Principle requires that there be multiple universes, each with different physical characteristics. I further argue that some modern scientific hypotheses relating to quantum mechanics and cosmology, if true, provide evidence for a multiverse with differing universes, which would allow the denial of the fine-tuning argument with the Anthropic Principle.

Introduction

In Section One of this paper, I examine the fine-tuning argument; the argument that the earth and the universe is ‘fine-tuned’ for humanity’s existence, and that this would be surprising without some intelligent agent creating the universe. Then, I present and discuss the Anthropic Principle, a typical response to the fine-tuning argument, which purports to show that our existence requires that the universe be fine-tuned and thus it is not surprising. I examine the three elaborations to the Anthropic Principle presented by John Barrow and J.D. Tipler and argue that the third–that the Anthropic Principle requires multiple universes to exist apart from our own and with different structures–can be empirically verified by modern science, and thus is worth investigating. Then, I separate the different types of coincidences which require fine-tuning into those which can be explained by known current science and those which require more speculation. The first category includes some coincidences which do not need strong anthropic reasoning (such as many evolutionary traits) as well as those which can be explained by a weaker version of the Anthropic Principle (such as coincidences regarding our place and time in the universe). The second category are those coincidences which require a stronger Anthropic Principle, which requires multiple universes; coincidences about the physical makeup of the universe. I examine what types of multiverses would satisfy this requirement of the Anthropic Principle. Finally, I explore topics related to the Anthropic Principle which may affect the conclusion it enables us to draw: whether we may reason from the existence of sapient life *to* a multiverse rather than vice versa, whether we can rationally predict the unlikeliness of the fine-tuned universe at all, and whether we will be able to explain the fine-tuned universe with a deeper, currently unknown Theory of Everything.

Section Two examines modern cosmological and physical theories and hypotheses to examine whether they allow for this stronger anthropic reasoning. I distinguish between multiverse models which permit typical, probabilistic anthropic reasoning and those which permit a stronger version where our universe's existence is guaranteed. I primarily discuss multiverse theories in terms of Max Tegmark's multiverse classification. According to Tegmark, a Level I multiverse is a much larger universe than our observable universe which encapsulates it, Level II is a multiverse comprised of bubble universes formed by the theory of Eternal Inflation, Level III is the Many-Worlds interpretation of Quantum Mechanics, and Level IV is his own idea of a mathematical ensemble universe. I then discuss cyclic multiverse models, and universes that exist not concurrently to our own but in different 'times'. I will argue that the anthropic principle only fully solves the fine-tuning problem if multiple universes with different physical characteristics exist in some sense.

Section 1: The Fine-Tuning Argument and the Anthropic Principle

The Improbability of a Life-Sustaining Universe

The universe seems 'fine-tuned' for the existence of human life. This fine-tuning is seen in the various physical structures and constants that make up our universe. In his book *Just Six Numbers: The Deep Forces that Shape the Universe,* astronomer Martin Rees establishes six such physical constants. One is the physical constant known as Ω (Omega), the ratio of the mass-energy density of the universe to the 'critical density', which determines the geometry of the universe; a ratio equal to 1 produces a geospatially 'flat', Euclidean universe. Were the ratio slightly higher than 1, the universe would collapse before life could exist, and if the ratio were lower, stars could not form. Other examples involve λ (Lambda, or the cosmological constant) and ε, the percentage of energy released by the nuclear fusion of hydrogen into helium. ε is determined by the strength of the Strong nuclear force, which binds protons and neutrons into nuclei. If any of these constants were slightly different than what they are, sapient life would not be possible; for instance, ε is roughly 0.007, but if it were 0.006, "a proton could not be bonded to a neutron and deuterium would not be stable", and if it were 0.008, "two protons would have been able to bind directly together […] so that no hydrogen would remain to provide the fuel in ordinary stars, and water could never have existed" (Rees, 1999, p. 48). The other numbers Rees proposes are N, the ratio of the strength of electromagnetism to that of gravity, Q, the amount of energy required to pull a galaxy apart relative to its mass-energy, and D, the number of spatial dimensions. They must fall into similarly narrow ranges. Often, as in William Lane Craig's "The Teleological Argument and the Anthropic Principle", other cosmic "coincidences" are seen to be fine-tuned, such as the capability of carbon to bond with itself or the earth being within the sun's relatively narrow habitable zone.

It is seemingly unlikely that conditions allowing sapient life to arise would occur in our universe by chance, were the conditions of the universe chosen at random–it is much more likely that the physical constants of the universe would be some set of constants that do not support human life. It seems like this improbability requires an explanation. A popular analogy compares it to a person winning ten lotteries in a row, each with 1 in 1000 odds–in such a scenario, we would not accept that this happened by pure coincidence. While we regularly accept even highly improbable scenarios occurring in our world–for instance, Leicester City winning the English Premier League in 2016–we seek to explain them, and we often try to find the most likely explanation. In the lottery example above, we would suspect foul play or a glitch in the randomization algorithm, since cheating and computer glitches are significantly more likely than one person winning ten lotteries in a row. The fact that our universe is capable of sustaining sapient life seems to require similar explanation. For the remainder of this essay, I will use the term SLC to denote sapient life capable; a SLC-universe is one which is capable of sustaining, or has the physical structures and constants in the narrow range which can sustain, sapient life such as humans. It is unclear just how unlikely it is for a universe to be SLC–a point to which I will return later in this essay–but it seems extremely improbable, enough so that positing an intelligent designer may be more likely than the universe simply occurring by chance.

Does God Explain Fine-Tuning?

Hugh Ross, in *The Creator and the Cosmos: How the Latest Scientific Discoveries Reveal God*, argues that the existence of dark energy, which is part of the mechanism for Ω, requires a fine-tuning of one in 10^{122}, and argues that this is so unlikely that it must come from a creator significantly more powerful than human scientists. Ross, and many others, makes an argument which, following the convention of the literature, refer to as the "Fine-Tuning

Argument”: that an intelligent designer, interested in creating sapient life, explains this fine-tuning. This argument relies on the process of looking for likelier explanations, as above: if the probability of the universe being SLC without a designer is close to zero, and the probability of the universe being SLC *given* a designer is close to one, it is likely that a designer exists, given that we know our universe is SLC. Even if we hold that a designer existing is unlikely in and of itself, according to proponents of this argument such as Ross, Craig, and Plantinga, it is more likely that a designer exists than that the universe came to be SLC by chance. The argument may be put into Bayesian form, paraphrased from Manson (2009), as follows:

K = Many of the initial conditions and free parameters of a universe need to be finely tuned in order for the development of life in that universe to be possible.

E = The universe is indeed fine-tuned for life.

D = A supernatural designer of immense power and knowledge exists.

(1) $P(E|K \& {\sim}D) \approx 0$

(2) $P(E|K \& D) \approx 1$

$\therefore P(D|E \& K) \approx 1$

Premise (1) is that the probability of the universe being fine-tuned given no designer is very low. Premise (2) is that the probability of the universe being fine-tuned given a designer is very high. Manson includes a third premise: $P(D|K) >> P(E|K \& {\sim}D)$, or the probability of a designer existing given the requirement for fine-tuning is much greater than the probability of the universe being fine-tuned with no designer. However, by applying Bayes’ theorem, this premise is unnecessary, as the conclusion derives from the first two premises alone. Manson notes that "no specific numbers are mentioned in the inequalities above. The numbers one gets depend upon whatever calculations of the evidence of fine-tuning one considers relevant, as well as on one's estimates of the intrinsic probability of D and of the probability of E given K and D" (2009).

One potential response to this argument is by rejecting premise (3) by arguing that the intrinsic probability of D is very low as well; in other words, arguing that God existing is so unlikely that it is in fact *less* likely that a designer exists than that the universe came to be SLC by chance. However, proponents of this argument would argue that there is other evidence for a designer; for instance, evidence for the likelihood of a designer may come from the simple preponderance of human belief in a designer God. Many other philosophical arguments support the existence of God, including Descartes's ontological argument and arguments from morality; these arguments are beyond the scope of this paper.

One may note that this argument does not make any particular God likelier than any other to be the designer without making further assumptions. Craig admits that "the postulate of a divine Designer does not settle for us the religious question" (1990). We may be able to intuit some things about the nature of the designer–for instance, the designer would be at least intelligent enough to know what physical constants can support sapient life–but religions make claims beyond this about their Gods. God sending His Son to die for our sins as claimed by Christianity, for instance, cannot be justified by such an argument. The argument may not even imply that a God exists, since other non-divine designers are possible. Scientists such as Alan Guth predict that as technology improves, humans may one day be able to create new universes. If universe creation is possible, our universe could have been created by aliens in another universe, who set the parameters of our universe to be SLC to observe the results or for reasons of their own design, reasons potentially unknowable to humans. Of course, this leads to an infinite regress; such aliens would have to have arisen in their own SLC-universe and so on. As well, a supporter of a religious designer may use a similar argument as above–there are a preponderance of beliefs about a divine designer, but few about alien designers–or one of the many other philosophical arguments in support of God.

The fine-tuning argument is one of a broader class of teleological arguments, or arguments from design, where it is argued that the existence of a designer, typically God, is probable due to evident signs of design in the universe. If the universe is highly likely to be designed, and not come about by random chance, there must be a designer. This argument was made famous by William Paley, who compares the universe to a highly complex machine such as a watch, arguing that if we found a watch on the ground, we would not suppose that it had come to be there naturally but had been designed. The fine-tuning argument holds that the sign of design is the improbability of a life-sustaining universe. A more general discussion on the teleological argument itself is beyond the scope of this paper, and it has been extensively discussed in the literature. Instead, I shall focus on the fine-tuning argument that justifies it. If the fine-tuning argument, and the further teleological argument, hold up, that would be a large change to human understanding; if it is likely that there is a designer, religions no longer must contend with the skeptical argument against God and can instead debate which conception of God is the most plausible. As such, it is important to examine responses to the fine-tuning argument and see if it stands up to scrutiny.

The Anthropic Principle

The most common response to the fine-tuning argument is known as the anthropic principle. This principle does not deny the low likelihood of the universe being so fine-tuned by random chance, but instead argues that it is still not unlikely that we find ourselves in an SLC universe. At its most broad, this principle states that the universe we observe must be SLC, simply because no universe which is incompatible with sapient beings could be observed by sapient beings. As such, it argues that the low probability of the universe being fine-tuned does not require explanation. The anthropic principle can be cashed out as an argument:

P1. Humans are sapient observers.

P2. Sapient observers could only exist in SLC-universes.

DC1. From P1 and P2, humans can only exist in SLC-universes.

P3. Humans exist in our universe.

∴ From DC1 and P3, our universe is SLC.

This basic formulation, however, is insufficient. If I made the argument that it was unlikely for Leicester City to win the Premier League in 2016, arguing that the probability of that event occurring is 1 because Leicester City *did in fact* win the Premier League in 2016 would not be a counterargument. John Leslie makes the same point with an analogy of a prisoner before a firing squad with fifty marksmen, all of whom miss; the condemned should not reason that it is unsurprising that they all missed because if they hadn't, he would be dead. These analogies imply that we should not explain improbable events occurring merely by noticing that they did occur.

In *The Anthropic Cosmological Principle*, John Barrow and J.D. Tipler examine three possible elaborations on the argument above. The first is that the universe must, for some reason, bring observers into being; in their words, "There exists one possible universe 'designed' with the goal of generating and sustaining 'observers'" (1986, p 22). However, this is not a response to the fine-tuning problem at all; it is merely the design question, restated and without using the word 'God'. According to Barrow and Tipler, this interpretation is "religious in nature" (22) and they do not discuss it further. Neither shall I. The second formulation is that "observers are necessary to bring the universe into being" (22). This idea is famously associated with physicist John Archibald Wheeler and is known as the Participatory Anthropic Principle. It seems *prima facie* absurd; there is a strong intuition that the universe exists whether humans are there to observe it or not, and that it did so for a significant period of time before observers. The second formulation, unlikely as it seems, may have support from quantum mechanics, particularly the von Neumann-Wigner interpretation; however, this interpretation is highly controversial, and the sheer implausibility of the universe requiring observers renders the second formulation highly implausible. The third formulation presented by Barrow and Tipler–and the one on which I will focus for the rest of this paper–is that an ensemble of different actual universes is required to justify the Anthropic principle.

My reason for ignoring the first elaboration should be obvious; it does not accomplish anything, as Barrow and Tipler admit. Why, however, ought I to spend the rest of this paper focusing on the third formulation to the deficit of the second? I focus on the multiverse version of the Anthropic Principle because, much more than the Participatory Anthropic Principle, can be tested by modern physics. The second formulation's basis in physics comes from a controversial, ill-understood interpretation of quantum mechanics, the von Neumann-Wigner interpretation. Empirical evidence can and has been gathered regarding this interpretation, in what are known as delayed quantum choice experiments, but it is unclear how to interpret the results of these experiments. Multiverse hypotheses, on the other hand, are well-established in cosmology and there is much more empirical evidence regarding them, which I shall show later in the paper.

The Multiverse Premise

How does having different actual universes justify the Anthropic principle? The answer lies in selection or survivorship bias. According to this version of the principle, sapient observers could only find themselves in universes which are SLC, so if there are enough universes such that it is likely that *some* or even one universe is SLC, we cannot help but find ourselves in that universe. The classic case of survivorship bias comes from World War II, when the Western Allies were seeking to optimize armor plating on their aircraft. Rather than put additional armor where they found bullet holes on returning aircraft, statistician Abraham Wald suggested they do the opposite. He reasoned that no bullet holes were found in other areas because aircraft could not survive hits to other areas, and so the only aircraft which survived to be investigated were ones which were hit in locations which were non-fatal.

Using this as an analogy, we can see how this applies to the anthropic principle. Humans could only exist in universes with conditions that allow humans to exist, as the only planes that could be investigated are planes which were not hit in specific locations. As such, we should not be surprised that our universe is SLC. In *The Salmon of Doubt*, Douglas Adams, as an analogy for the fine-tuning argument, asks us to "imagine a puddle waking up one morning and thinking, 'This is an interesting world I find myself in–an interesting hole I find myself in–fits me rather neatly, doesn't it? In fact it fits me staggeringly well, must have been made to have me in it!'" (2002). We can see here the role selection bias plays in the anthropic theory. The hole the puddle is in is not made for it, but the *puddle fits the hole* because of the shape of the hole. It only appears to the puddle, necessarily the same shape as the hole, that the hole was created in the shape of the puddle. As a further analogy, Nick Bostrom argues that if you catch 100 fish each larger than six inches, you ought not conclude every fish in the lake is larger than six inches "if your net can't catch smaller fish" (2010). The puddle could only have the shape it has in an appropriately shaped hole, and the only fish we can catch are those which can be caught by our net. Similarly, we could only exist in a universe appropriate for our existence.

Using this selection bias to explain why *our* specific universe is SLC, however, does not explain why there is an SLC universe to begin with. For this, we require an additional premise: that it is likely that at least one SLC universe exists. Without a multiverse, then, we are in the same situation as before; we must reject the argument that it is unlikely that the universe would be fine-tuned without a designer. With a sufficient multiverse, however, we can accept that argument but still hold that it is unsurprising that our universe is SLC. By a 'sufficient multiverse', I mean one with many universes with different characteristics, such that it is likely that at least one universe is SLC. This is what I take to be the Strong Anthropic Principle with a Multiverse:

P1. Humans are sapient observers.

P2. Sapient observers could only exist in SLC-universes.

DC1. From P1 and P2, humans can only exist in SLC-universes.

P3. **A sufficient number of universes exist, some of which have different features and constants and thus a different structure, such that it is probable that at least one SLC-universe exists.**

P4. Humans exist in our universe.

∴ From DC1, P3, and P4, it is not surprising that our universe is SLC, as it is likely that at least one universe is SLC and we could only inhabit those universes.

Premise 3, or the Multiverse Premise (MP), is the main new premise here, and it is also the one most in need of support; my project in section 2 is to determine which scientific hypotheses support premise 3.

Note that variants of premise 3 are required to explain other types of coincidences. For the Anthropic Principle to explain any seeming coincidence, premise 3 requires that there be a range of options to choose from. For instance, if we try to justify the seemingly fine-tuned position of earth relative to the sun using the Anthropic Principle, we must appeal to multiple planets with different positions relative to their stars, if we use the Anthropic Principle to explain the age of the universe, there must be a plurality of ages the universe could be, et cetera. This is why in order to explain coincidences about the structure of the universe, multiple universes with different structures are required. The Weak Anthropic Principle, discussed by Barrow and Tipler, uses similar reasoning, but restricts itself to our place in our own universe. As such, it is meant to answer the argument that our position in our universe, both in time and space, also seems privileged. Earth is within the relatively narrow habitable zone of the sun, and the age of the universe is such that main-sequence stars such as the Sun can exist. Instead of the Multiverse principle, then, the WAP requires a weaker third premise; that planets may form at different distances from their star, and that the universe has a different state at different times. These premises are easy to accept given recent science. It has been known since Copernicus that planets can form at different orbital lengths, and modern telescopes such as the Kepler space telescope are even powerful enough to observe planets orbiting around other stars, including in the habitable zones of those stars. Big Bang Theory holds that the universe changes over time; for instance, the fundamental interactions only began less than a second after the Big Bang, and stars did not begin to form until hundreds of millions of years following the Big Bang. However, the stronger anthropic principle, which requires a multiverse, treads on much shakier scientific ground for justifying premise 3, the multiverse premise.

Three Classes of Coincidence

The coincidences which make up the fine-tuning problem can be separated into three main groups. First, some involve facts about our evolution as a species. Second, some involve facts about our place and time in the universe. Third, some take the form of facts about the universe, such as Ω or the strength of the Strong force as described above.

I will address the first category briefly here. Many skeptics of evolution argue that there are coincidences in modern humans which require intelligent design. A common (though out of context) quotation of Darwin's *On the Origin of Species* regards the evolution of the eye, which, according to Darwin, "seems, I must confess, absurd in the highest possible degree" (1859). While this particular example clearly lacks context–Darwin argues in the next paragraph that if each small gradation towards the modern eye yields some small benefit, it is possible that the eye will come about via evolution–even modern biologists such as Stephen Jay Gould argue that if the 'tape of life' were replayed, it is unlikely that the same results (that is, humanity) would occur. We might then wonder if it is surprising that humanity arose even given a life-sustaining universe and planet on which to arise. However, we ought not regard features particular to humans, apart from sapience, as requiring explanation. This is due to the same survivorship bias that explains why we should not ask why our particular universe is SLC, but rather whether some universe is SLC. We can only observe our own evolution–had we evolved in a different way, we would observe that instead. It may seem surprising that humans have 10 fingers, as opposed to, for instance, 12; some aspects of our bodies are causally explained by evolution, such as our having opposable thumbs (which enabled much greater tool use), but we might wonder why, in particular, it is humans and not something else that evolved. It is at least partially arbitrary, but if we had 12 fingers, we would wonder the same thing; why do we have 12 and not 10? Other features of humans are also like this; even if the tape of life replayed in a different manner, all that is required is for it to produce sapient life, not sapient life of our particular kind.

Beyond this, there are coincidences regarding our place and time in the universe. Life can only arise at certain times and places in the universe, since only certain types of stars can support planets where life can arise, and such stars can only form with particular preconditions. We could not, for instance, come to exist a few hundred million years after the big bang; the universe would be much too hot, there would be no metals created by supernovae to support life, and stars like the Sun could not yet reach the age where they could have planets. As well, recall that our planet is located suitably far from our Sun such that life is possible. The zone around a star in which life is possible is not clear, with different estimates of planetary structure yielding different results, but it is clear that there is a specific zone around a star where life is possible; too close, and the greenhouse effect will render the planet waterless, while too far and all water will freeze. Earth sits within that zone. Some recent estimates of the size of the habitable zone are 0.99-1.68 AU (1 AU is the average distance between the Earth and the Sun) by Kopparapu et al (2013), and 0.95-2.4 AU by Ramirez and Kaltenegger (2017). These coincidences are easy to explain with a weaker anthropic principle. It is plainly obvious that there are different times, and we will find ourselves at a time which supports our existence. Also, there is substantial observational evidence that planets apart from Earth exist at differing distances from their stars; modern observatories have discovered many planets within the habitable zones of their stars. As well, we have good evidence that such stars and planets existed far in the past, totally independent of humans; due to the nature of light, the stars we observe let off their light far in the past, some well before humanity existed. Since a range of times and places exist in the universe, such that ones which support sapient life are possible, and since we could only exist at a time and place that supports our existence, it is not surprising that our time and place in the universe does in fact support our existence. The Weak Anthropic Principle, thus, has well-grounded scientific evidence to support it–we need not be surprised that our time and place in the universe is one that is friendly to life.

This leaves the final class of cosmic coincidences; those which have to do with the structure of our universe. Rees's six numbers are examples of this sort. Others have proposed different examples, such as the energy level of Carbon-12, known as the Hoyle State–if it were much lower or higher, not enough carbon could be generated to support life. These types of fine-tuning are not dismissed as easily as the previous ones, because we only know of our own universe, where Rees's constants and the Hoyle State are as they are. Indeed, at present it is believed that we only are capable of directly observing our own observable universe, as I will establish below. Thus, the stronger Anthropic Principle is required to argue against the surprisingness of these coincidences; the stronger principle which posits some sort of multiverse. In section 2, I will examine modern cosmological hypotheses about our universe and beyond in order to see which hypotheses, if correct, would allow the stronger Anthropic Principle to fully dispel the fine-tuning argument. Before I do so, however, I will examine a few related arguments to the Anthropic Principle.

Can The Existence of Sapient Life Justify the Multiverse?

Roger White, in his paper “Fine-tuning and Multiple Universes”, argues that the multiverse hypothesis does not permit us to avoid fine-tuning. He differentiates between the probability of our particular universe being SLC, and the probability of there being an SLC universe. The multiverse premise only states that it is likely that some universe is SLC, but not that it is our particular universe. As such, we might still be surprised that the universe which we happen to inhabit is SLC, and not some other which we do not. This, however, is why we must consider the survivorship bias mentioned earlier. Sapient life could only arise in an SLC universe, so if some universes are SLC, those are the only ones where humans could arise, and thus the only ones that we could observe. This is the purpose of DC1 (‘Humans can only exist in SLC-universes) in the line argument above. We should not treat our particular universe as requiring its own explanation; if we accept the multiverse hypothesis, it becomes likely that some universes are SLC, and then the Anthropic Principle explains why ours is.

White also argues against a similar principle, which is worth discussing; that the fine-tuning of our universe itself justifies the multiverse hypothesis. This argument is tempting, particularly if one wishes to use the Anthropic Principle by itself as more than a response to the Fine-tuning argument but as evidence against an intelligent designer. However, we can not argue from the fact that our universe is fine-tuned to the conclusion that a multiverse must exist. According to White, with M being the Multiverse hypothesis, E being ‘Our universe is life-permitting’, and E´ being ‘Some Universe is life-permitting’: "What matters is the probability of M given E´ and E. But now since E entails E´, (E´ & E) is equivalent to E. So P(M|E´ & E) = P(M|E). But […] P(M|E) is just equal to P(M)” (2000). The probability of the multiverse hypothesis remains the same regardless of our universe being SLC. White concludes at the end of his paper that “if we happened to know, on independent grounds, that there are many universes […] our knowledge of the existence of many universes would render the fine-tuning of our universe unsurprising. However […] our good fortune to exist in a life-permitting universe gives us no reason to suppose that there are many universes”. We must, therefore, support the existence of the multiverse with other, independent evidence.

How unlikely *is* fine-tuning?

Until now, I have largely avoided actual probabilities. I did not argue for just how unlikely fine-tuning is, merely stating that it “seems very unlikely”. As well, I did not argue how many universes would need to be present in a multiverse to sufficiently dispel this unlikeliness, simply that there be “enough to make at least one SLC universe likely”. This is because it is impossible to say for sure just how unlikely the fine-tuning of the universe actually is. In an Aeon article entitled, “Why does our universe appear specially made for us?”, Tim Maudlin argues that “it is not at all clear what it means to say, in this context, that the particular values that obtain were ‘improbable’ or ‘unlikely’” (2013). That we don’t know just how unlikely the fine-tuning of the universe is seems to be more of a problem for the intelligent design side. The Anthropic Principle is primarily used as a counter-argument against the Fine-tuning argument, and it does not rely on the fine-tuning not being unlikely. Rather, it argues that even if fine-tuning of this universe is unlikely, it still does not require further explanation that the universe is observably SLC. By contrast, if our universe having the values it has is *not* unlikely, the Anthropic Principle is unnecessary, since the fine-tuning argument is rejected by that fact alone.

Maudlin’s article raises a further objection, which seems to cause problems both for Fine-tuning argument supporters and for supporters of a multiverse hypothesis. We may just think the fine-tuning is unlikely, but there may yet be a scientific explanation to why the values are what they are. “Some physicists […] would prefer a physical theory that yields the emergence of these structures as typical and robust phenomena, not hostage to a fortunate throw of the cosmic dice that set the values of the constants […] if a ‘constant of nature’ is really a fixed value, then it was not the product of any chancy process” (2000). It is possible that the constants that seem fine-tuned to us are explainable by a more accurate theory of the physics surrounding the universe, just as the once-surprising human eye is explained by evolution and is no longer considered surprising. However, as Maudlin concludes, no such theory is yet known, and “our modern understanding of cosmology does demote many facts of central importance to humans–in particular the very existence of our species–to mere cosmic accident […] In the end, we might just have to accommodate ourselves to being yet another accident in an accidental universe”. And even if some Grand Unified Theory of Everything is found, describing why our universe is the way it is, we are still left with the question which Max Tegmark (2003) attributes to John Archibald Wheeler: *Why these equations and not others?* Finding a Theory of Everything may not solve the fine-tuning problem, and even if it would, we have not yet found such a theory. As such, I will now turn to hypotheses current science is considering regarding the multiverse, and examine whether they are sufficient to justify the multiverse premise listed above if validated independently (‘A sufficient number of universes exist, some of which have different features and constants and as such have a different structure, such that it is likely that at least one existing universe is SLC’).

Section 2: Multiverse Theories

Many universes or all possible universes?

By definition, our observable universe is all we can possibly observe. It is defined as the region around each observer where light would have the capability to reach in the lifespan of the universe. Given the status of the speed of light as a ‘cosmic speed limit’, which nothing can exceed, nothing outside this region could possibly interact with us in a way that we could observe it. A naïve calculation would suggest that this is a sphere with the radius of the speed of light times the age of the universe; however, it is larger than this, due to the universe’s inflation (expansion faster than the speed of light) shortly after the Big Bang. Any light emitted outside this region has not yet had the time to reach us, and as such cannot be observed. Because of this, hypotheses that posit multiple universes are strictly speculative. That has not stopped a variety of multiverse hypotheses from coming to the fore. Multiverse hypotheses are present in much popular entertainment–for instance, the incredibly complex multiverse of Marvel Comics, each universe of which has its own Spider-Man, or the mirror dimension of the Star Trek episode “Mirror, Mirror”–but some are more seriously scientific. While these hypotheses remain untested, they may one day be testable, either indirectly by using new scientific techniques or directly if it is somehow possible to observe extra-universal objects or events. Thus, we may ask which hypotheses support the Multiverse Premise required by the Anthropic Principle to dispel the fine-tuning argument.

Here I wish to distinguish between two types of sufficient multiverse hypotheses. Recall that for a multiverse to be sufficient to allow the anthropic principle, there must be enough universes with different characteristics such that at least one SLC universe is likely. Some multiverse hypotheses hold that a great many universes exist and that their physical properties and laws may differ, and these I hold to be sufficient for the anthropic principle so long as they predict a suitably large and varied ensemble. Some hypotheses go farther in their predicted multiverse and predict that *all* possible universes which could exist do exist. These hypotheses render any probabilistic thinking moot, as such:

P1. A universe having the physical characteristics of our own is possible.

P2. All possible universes exist.

∴ From P1 and P2, a universe having the physical characteristics of our own exists.

P1 is plainly obvious, given that our universe has its own physical characteristics and exists. If we accept P2, a universe with our exact physical characteristics is guaranteed to exist. Thus, we should not be surprised at all to find ourselves in it, based on the survivorship bias of the anthropic principle.

I will distinguish between these two types of hypotheses; for those of the first type, additional arguments are required, namely that there are enough universes to create a suitable ensemble, and for those of the second type, no additional arguments are required–if those views of the multiverse are somehow validated, the fine-tuning problem will be of no consequence at all.

Cosmologist Max Tegmark classifies multiverse hypotheses into four levels: (I) An infinite universe beyond our own observable universe, (II) a chaotically inflating universe in which some pockets stop expanding, forming their own universes, (III) the Many-Worlds Interpretation of Quantum Mechanics, and (IV) an ultimate ensemble, in which the multiverse is a mathematical structure in which all substructures, including universes with every combination of physical constant exist. The first is based on the observation that the observable universe does not comprise all of space. The second is based on the theory of eternal inflation, developed by Guth, Steinhardt, Vilenkin, and Linde; in this theory, the total universe is a rapidly inflating 'false vacuum energy', where sections collapse and form pocket or bubble universes, of which our universe is one. The third hypothesis is based on Hugh Everett's many-worlds interpretation of quantum mechanics, in which every quantum event splits into two separate worlds, each equally existing, one in which the wavefunction collapses one way and the other in which it collapses the other way. The fourth hypothesis is Tegmark's own; that the universe, and everyone in it, is a mathematical structure and that all such structures are equally existing, allowing for every possible universe to be realized. I will examine each hypothesis to determine if it is sufficient for the multiverse premise in the anthropic principle.

Infinite universe beyond our borders

According to current cosmology, the observable universe does not comprise the entire universe, only the part of it we can observe given the amount of time light has had to travel since the Big Bang. In fact, the 'observable universe' at each point in spacetime is different, since light from a particular direction can reach someone in that direction sooner than someone else. This implies that space extends beyond our observable universe. For instance, if I am 5 feet from you, the 5 foot region at the very edge of your observable universe does not exist in mine, but the intuition is that that region exists even if I cannot observe it. It follows, therefore, that something outside of our observable universe exists, though what is outside of it is, by definition, unobservable. Is what exists outside of the observable universe simply infinitely more space? Tegmark puts it this way: "It is difficult to imagine that space could *not* be infinite–for what would lie beyond the sign saying, '*SPACE ENDS HERE–MIND THE GAP*'" (2003)? While space could be non-Euclidean–perhaps shaped like a sphere or a torus–evidence supports a mostly flat space. According to Tegmark, there is not only evidence for a flat, infinite space, but evidence that it is "teeming with galaxies, stars, and planets." Such an infinite universe contains an infinite number of Hubble volumes, or observable universes centered around a point as described above.

However, such a multiverse is not suitable for the Anthropic Principle. While different Hubble volumes may have differing initial conditions–and in fact, with an infinite volume, any set of initial conditions with non-zero probability will be realized an infinite amount of times–they follow the same laws of physics as the observable universe. According to this hypothesis, the Hubble volume centered on me is a separate ‘universe’ than the Hubble volume centered around you, and yet we hold that the laws of physics are the same for me and for you. There is no reason not to generalize this to all Hubble volumes, even in the infinite universe, unless the laws of physics can vary in separate regions of spacetime. This leaves us with the question of why the laws of physics of the infinite universe are conducive to life, and as such does not solve the fine-tuning problem; a defender of fine-tuning would argue that it is surprising that the universe as a whole has the laws of physics that it does.

Eternal Inflation and Bubble Universes

Around 1930, Edwin Hubble discovered a fact which would deeply influence Big Bang cosmology: the light from distant galaxies is redshifted, or more towards the red end of the color spectrum then we would expect them to be if the universe were expanding evenly. Additionally, the more distant the galaxy, the more redshifted the light emitted from it. This implies that the further a galaxy is from Earth, the faster that galaxy moves away from Earth; distant galaxies appear to be accelerating away from us. Big Bang theory explains why galaxies appeared to be moving away from Earth–if the volume of the universe is expanding, objects in the universe will be pushed apart by the expansion of space. A common analogy is a loaf of bread with raisins inside being baked; as the bread rises, the raisins inside the bread increase in distance from each other proportionately to the expansion of the bread. The acceleration of expansion, however, was not initially explained, since it would require that the expansion of the universe is itself accelerating, which would seem to contradict the Big Bang theory in part–if the expansion was caused by a single Big Bang, there would need to be another force causing the rate of expansion to increase.

In 1979, Alan Guth attempted to solve this problem, along with other problems in physics such as the lack of magnetic monopoles, magnets with only one pole predicted by Paul Dirac's theory of quantum energy, and the overall flatness and homogeneity of the universe (the relatively even distribution of matter and energy in the universe, on a very large scale). Guth argued that the observable universe is one part of a much larger universe, as in Tegmark's Level I, and that very shortly after the Big Bang, the universe exponentially expanded in size, becoming far larger than would be expected by the standard Big Bang model. This inflation, as it is called, was caused by false vacuum energy. The universe was a vacuum, but a not-entirely-empty one, and one that was unstable–the vacuum could decay to a lower energy state. This decay caused the pressure of the false vacuum to be negative. According to Guth, "A negative pressure […] creates a repulsive gravitational field. […] A short calculation shows that the gravitational repulsion causes the universe to expand exponentially" (1997, p. 173). This inflationary theory also explains why the universe is flat on a large scale–any differences in the initial conditions would be stretched out by inflation and appear uniform, like a tattoo when skin expands. Magnetic monopoles are similarly diluted by this expansion.

Later theorists including Paul Steinhardt, Alexander Vilenkin, and Andrei Linde developed Guth's inflationary theory into what we now know as eternal, or chaotic, inflation. According to this theory, the inflationary period lasts forever throughout most of the universe, but in some areas the false vacuum decays, and these bubbles become hot, homogenous universes. Our own observable universe is one such bubble universe; the expansion of the universe is accelerating due to the background inflation of the multiverse, like an expanding pocket of gas in a rising loaf of bread. These bubble universes form Level II in Tegmark's taxonomy.

Are these bubble universes like the Hubble volumes of Level I; many different universes, but each with the same properties and laws of physics? In fact, the bubble universes of Level II can have different properties, and as such would be suitable for the Multiverse premise. Quantum mechanics–which I will discuss further in the next subsection–causes the false vacuum state to delay not fully deterministically, but probabilistically, and in different ways, since there are different vacuum states the false vacuum could decay to. This means that the bubble universe forming where the false vacuum has decayed a certain way due to quantum fluctuations would have different physical properties as one where the false vacuum decays in a different way. For instance, quantum effects could cause the Calabi-Yau manifold–a structure implied by string theory which is how the extra dimensions in string theory are curled up, or 'compactified'–to curl all but three dimensions, leading to a three-dimensional space as in our universe, or in all but seven dimensions, leading to a seven-dimensional space. The dimensionality of space determines many of the physical properties of space. As well, other physical constants could differ across different bubble universes. According to Tegmark, "The Level II multiverse is therefore likely to be more diverse than the Level I multiverse" (2003). "Although the fundamental equations of physics are the same throughout the Level II multiverse, the approximate effective equations governing the low-energy world that we observe will differ" –so while the fundamental laws of physics remain the same, the physical characteristics that make up the fine-tuning argument would change, allowing eternal inflation-style multiverses to satisfy the multiverse premise.

Additionally, the eternal nature of the inflation implies that inflation does not end, but continues forever, with new bubble universes constantly being created. Given this, over a suitably long period of time, an SLC universe is bound to arise, however improbable–in fact, over time, all possible configurations of bubble universes will come to exist. Eternal inflation places some restrictions on what kind of universes can exist–all bubble universes must follow the same fundamental laws of physics, though the initial conditions and physical characteristics may change between them. However, eternal inflation, if verified, would likely be one of the second class of multiverses, which remove probability entirely from the equation.

The Many-Worlds Interpretation of Quantum Mechanics

According to the standard view of quantum mechanics (QM), nature does conform to the laws of classical, deterministic physics. Rather than existing at a particular place and time, until they are interacted with, particles exist as a wave function, or a probability field of where they might be. The wave function of a particle is the probability of measuring it at a certain point. Once the particle is measured, the wave function collapses into one of the points where it could be measured. This seems very odd to our ears–why should a particle only 'decide' to be where it is when it is observed? Modern interpretations of QM do away with the concept of measurement-induced wave function collapse, instead arguing that when a particle is measured, it becomes entangled with the measuring apparatus, and they are treated as one system. QM has been experimentally validated at subatomic scales and is thought to describe events occurring at such scales–at the macroscopic levels we deal with, classical physics is a good enough model. However, it is clear that QM determines interactions at all scales, up to and including the universal or extra-universal level.

Due to its strangeness, many different interpretations of quantum mechanics have been proposed. The Many-Worlds Interpretation (MWI), proposed by Hugh Everett in 1957, is meant to resolve the non-determinism of quantum mechanics, where systems are in a superposition of possible states before being observed and collapsing into one actual state or another probabilistically. According to MWI, the wave function does not actually collapse but instead decoheres; in other words, at each quantum event, the world 'splits' into one world where the wave function collapses one way and another where it collapses the other way. In the famous thought experiment of Schrödinger's cat, a cat is placed in a box, the inside of which cannot be observed, and a quantum decay determines whether poison is released into the box or not. The cat is said to be in a superposition of states, being alive and dead at once until observed. MWI resolves this seeming paradox–how can the cat be both alive and dead?–by hypothesizing that in one world, the cat remains alive, and in the other, the cat dies. The primary argument of MWI is that this splitting occurs for all quantum events, meaning that all possible outcomes are realized in a separate world. The reality described by MWI is one in which many universes exist–in fact, all of them that could possibly exist. Thus, MWI seems to be a hypothesis of the second type distinguished above, which removes probability from the Anthropic Principle altogether; since a universe with our physical characteristics is clearly *possible*, MWI would make it completely unsurprising that it exists and that we are in it.

However, this does depend on when the first split occurs. MWI holds that every quantum event produces such a split–essentially, a branching tree of history. Prior to the Big Bang, there were no events or history in the traditional sense, since time did not exist. It seems intuitive that the laws and physical characteristics of our universe would not come into existence after our universe did, as we think of them as interwoven into the universe's existence. If that is the case, when the universe came into existence, it would have done so with the specific characteristics it has intact, and they would not have been subject to quantum changes. As such, the MWI would not predict the many worlds each have their own physical characteristics, as required by MP, but instead that they all share the same characteristics. We would then be faced with a surprisingness problem of why the initial conditions were ones favorable to life, and MWI would not allow us to apply anthropic reasoning.

If, however, the characteristics of the universe were subject to quantum events, MWI would imply that there exist universes with all characteristics, as in the argument above. This seems unintuitive, but is possible. One observation of modern physics is that time is quantized; it is impossible to observe any amount of time less than the Planck time, around 10-43 seconds. For that length of time following the Big Bang, the universe was in the Planck epoch, and at that time scale the laws of physics as we know them break down. It is possible that the physical characteristics were in fact formed during that time. Leonard Susskind and Raphael Bousso, in *The Multiverse Interpretation of Quantum Mechanics*, argue that “the many-worlds of quantum mechanics and the many worlds of the multiverse are the same thing” (2011). If they are right, MWI worlds would have different constants and characteristics, similar to the bubble universes discussed earlier, where the bubble universes have different characteristics caused by quantum fluctuations. Al Wilson (manuscript) argues that whether MWI supports the multiverse premise depends on the quantum probabilities assigned to each potential outcome; if the quantum probabilities of life-sustaining properties are higher, we may still need to rely on a designer to explain why those probabilities are higher. However, Bousso and Susskind’s view is that the physical constants are dependent on the Calabi-Yau manifold, as discussed in the section above. According to Wilson, Bousso and Susskind show that there would be multiple worlds "corresponding to all possible compactifications […] mak[ing] fine-tuning evidence entirely unsurprising". While it is not completely clear that MWI is suitable for the multiverse premise, it seems likely that it is, and if it is, it is an example of the second type of multiverse theory, which removes probability from the anthropic principle altogether.

An Ultimate Mathematical Ensemble

Suppose, as in Section 1, that there exists a Theory of Everything, which describes the processes of the universe by a mathematical equation, or set of mathematical equations. As Tegmark ascribes to Wheeler, we may ask the question: *Why these equations and not others*? Tegmark's hypothesis, however, is that while our world is such a mathematical structure, all such structures are real. What Tegmark means by the world being a mathematical structure is that "mathematical equations describe not merely some limited aspects of the physical world, but *all* aspects of it. It means that there is some mathematical structure that is what mathematicians call *isomorphic* (and hence equivalent) to our physical world, with each physical entity having a unique counterpart in the mathematical structure and vice versa" (2003). This is similar to the traditional way of thinking of classical physics, in which the universe behaves deterministically according to its laws and initial conditions, and indeed has roots in western thought tracing back to Plato. Everything in the universe, including living beings, are mathematical substructures–a set of equations within the larger mathematical structure of the universe. Tegmark defines a mathematical structure as having 'physical existence' "if any self-aware substructure (SAS) [for instance, a self-aware human] within it subjectively […] perceives itself as living in a physically real world." His hypothesis is that all mathematical structures have physical existence, and as such the multiverse is an 'ultimate ensemble' of all possible mathematical structures, or variations of the laws of physics. Such a multiverse would seemingly justify the anthropic principle, and the second, stronger version to boot.

Is such a theory plausible? It is at least plausible that the universe is a mathematical structure and that we are substructures within it. However, Tegmark does not provide much evidence for his assumption that all mathematical structures exist. In fact, there is a contradiction in his definitions: he defines a mathematical structure as having existence if a substructure within it perceives itself as living in a physically real world, but this would seem to exclude universes which cannot produce self-aware substructures–or, in other words, sapient life. As such, its sufficiency for the anthropic principle is also unclear. If only universes which can permit sapient life are allowed, we might ask ourselves why the multiverse is so friendly to life. Tegmark seems to hold that not only universes with sapient life exist, though it is unclear how he does so given his definition of physical existence. There is a further problem, however. For evidence of a Level IV multiverse, as he calls it, Tegmark argues that it answers the question posed by Wheeler: *Why these equations and not others*? But as discussed in Section 1, we can not argue from the fine-tuning of the universe to the existence of the multiverse. While Tegmark's Level IV multiverse would likely justify the anthropic principle, it is implausible as an answer in and of itself.

Cyclic Universes

Could other types of multiverses support the Anthropic Principle? We may note that it is not required for multiple universes to exist at once for MP to be justified. If universes with differing characteristics exist separately in absolute time from each other, we can dispel the coincidence of being in a universe existing at this time in the same way as we do of all time-and-place coincidences. This allows MP to be justified by another type of multiverse as well; a cyclic one. One such model, explored by Stephen Hawking (1980), is the Big Bounce model, in which following a period of expansion, the universe begins to contract back into a singularity. Once it fully contracts, a new Big Bang occurs, potentially with different physical characteristics. If that model is correct, our universe is just one of a potentially endless cycle of universes; and if these universes can have distinct physical characteristics, MP is justified. Notably, the Big Bounce model is a contrast with the eternal inflation model, as they contradict each other; while it is possible neither is correct, they both provide support for the Anthropic principle. As well, other cyclic models could provide support for MP, such as Conformal Cyclic Cosmology, in which eventually, a universe becomes so spread out that all matter decays, such that there is nothing in the universe which can be described by time or space–the conditions required for the Big Bang. In either cyclic model, what is required to support MP is that different iterations of the cycle can have different physical characteristics.

Such cyclic models may be either the first, probabilistic variety of multiverse theory or the second, depending on whether the recurrence is infinite. If so, as with eternal inflation, universes with each type of condition will arise infinite times, and our universe is guaranteed to exist. If the cycles have a beginning and terminating condition, however, it is unclear how many cycles would occur. If this is the case, more information about the nature of the cycles is required to determine if enough universes with different conditions occur to meet the requirements of the multiverse premise.

Is this all scientific?

Throughout section 2, I have referred to each scientific idea presented as a hypothesis. This is intentional. Since, by definition, we cannot observe universes apart from our observable universe, empirical evidence of universes apart from our own seems incredibly difficult if not entirely impossible. As such, these hypotheses may be purely speculative. If multiverse hypotheses are untestable, they are unfalsifiable. According to Karl Popper's view of science they are thus unscientific, as "statements or systems of statements, in order to be ranked as scientific, must be capable of conflicting with possible, or conceivable observations" (1962). What, then, is the point of this? The project of this paper is to examine whether the anthropic principle can be supported by scientific arguments, and if multiverse theories are unscientific, we are back to where we started.

While multiverse theories are not directly verifiable, however, we can gain empirical evidence for (and against) them. The various multiverse theories presented above make empirical predictions about our own universe which can be tested–as such, they pass the falsificationist test. For instance, the theory of eternal inflation on which the level I and II multiverses rest "makes specific, quantitative predictions for severable observable quantities, such as the flatness parameter ($\Omega_k = 1 - \Omega$) and the spectral tilt of primordial curvature perturbations ($n_s - 1 = d \ln P_R / d \ln k$), among others–predictions that match the latest observations from the *Planck* satellite [referring to the results of the European Space Agency's 2013 *Planck* mission] to very good precision", according to Guth et al (2013). Tegmark, as well, lists evidence for all four levels of multiverse classification, and argues that multiverse theories can be tested and falsified: "Containing unobservable entities does clearly *not* per se make a theory non-testable. For instance, a theory stating that there are 666 parallel universes, all of which are devoid of oxygen makes the testable prediction that we should observe no oxygen here, and is therefore ruled out by observation" (2003).

Further, the lack of current testability of multiverse hypotheses does not mean that they are unscientific. We may yet find new ways to test these theories more directly. The Big Bang Theory, for instance, was proposed in the 1920s and popularized in the 1950s, and was accepted by cosmologists despite a lack of direct observational evidence until the COBE satellite directly measured the cosmic microwave background radiation of the universe in 1990, providing direct empirical evidence confirming the predictions of the Big Bang model. Physicists may argue about whether eternal inflation is an accurate model given current evidence or over which interpretation of quantum mechanics is correct; these are new questions in the field of physics which require more research and evidence. However, no one denies that multiverse theories make predictions about our own observable universe, and that we can obtain empirical evidence that confirms or disconfirms those predictions. As such, these hypotheses are scientific, even if unconfirmed, and a discussion of their impacts in philosophy is appropriate.

Conclusion

The universe seems fine-tuned to permit the existence of sapient life, in particular human life. It seems to be unlikely that this would occur by chance, leading some to use this as evidence of cosmic design in a teleological argument for a designer, typically God. The Anthropic Principle aims to rebut that argument by showing that due to selection bias, the only universe which we could observe is one where sapient life is capable. In order to dispel the fine-tuning argument, it needs a range of possible options for what it is explaining to select from–in the case of coincidences about our planet’s position in space, it needs multiple planets at different positions relative to their stars to select from, while in the case of physical characteristics of our universe, it requires multiple universes with different characteristics to select from. The first is readily evident to modern science, and indeed to anyone with a telescope, but the second is by definition hypothetical. Many serious scientific hypotheses, however, posit the existence of multiple universes, and if confirmed would thus give weight to the anthropic principle. These theories may differ in the type of multiverse they predict, but we can determine whether the theories support the multiverse required for the Anthropic Principle or do not.

A few words of caution are needed. The first is that we must be cautious of anthropomorphizing sapience–it may be that sapient life can exist in some form totally different than what we experience. If so, the range of physical characteristics required for sapient life is wider than we may conceive. As well, the fine-tuning argument, and thus the anthropic principle, are statistical arguments based on 'surprisingness', a term which is hard to define. It is possible that there exists only one universe, not designed with the intention of sustaining life but doing so anyhow, simply due to the underlying order of the universe, as discussed in section 1; while such a scenario would be surprising, we accept various 'surprising' facts once given evidence for them, such as chickens being able to live without their heads. Thus, this entire debate may be pointless, though I imagine if such underlying order was found, the debate would merely shift to, as Tegmark ascribes to Wheeler: *Why these equations and not others?* As well, either side of the debate doesn't establish much–even if it is surprising that the universe is fine-tuned, that only provides evidence for some designer, not proof and not even evidence for any particular designer. As well, if the Anthropic Principle holds, it tells us nothing about the actual state of the universe or multiverse; it may be that the Anthropic Principle holds and yet that God exists and designed the multiverse. Regardless, it is an important debate since it speaks to the ultimate reason for human existence. It is important to know whether the Anthropic Principle is justified, and modern and future science can enable us to do so.

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