FINE-TUNING ARGUMENTS IN COSMOLOGY

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The aspect of anthropic reasoning that has attracted most attention from philosophers is its use in cosmology to explain the apparent fine-tuning of our universe. “Fine-tuning” refers to the supposed fact that there is a set of cosmological parameters or fundamental physical constants which are such that had they been very slightly different then the universe would have been void of intelligent life. For example, in the classical big bang model, the early expansion speed seems fine-tuned. Had it been very slightly greater, the universe would have expanded too rapidly and no galaxies would have formed; there would only have been a very low density hydrogen gas getting more and more dispersed over time. In such a universe, presumably, life could not evolve. Had the early expansion speed been very slightly less, then the universe would have recollapsed within a fraction of a second, and again there would have been no life. Our universe, having just the right conditions for life, appears to be balancing on a knife’s edge (Leslie 1989). A number of other parameters seem fine-tuned in the same sense – e.g. the ratio of the electron mass to the proton mass, the magnitudes of force strengths, the smoothness of the early universe, the neutron-proton mass difference, even the metric signature of spacetime (Tegmark 1997).

Some philosophers and physicists take fine-tuning to be an explanandum that cries out for an explanans. Two possible explanations are usually envisioned: the design hypothesis and the ensemble hypothesis. Although these explanations are compatible, they tend to be viewed as competing: if we knew that one of them were correct, there would be less temptation to accept the other.

The design hypothesis is that our universe is the result of purposeful design. The "agent" doing the designing need not be a theistic God, although of course that is one archetypal version of the design hypothesis. Other universe-designers have been considered in this context. For example, John Leslie (Leslie 1972, Leslie 1979, Leslie 1989) discusses the case for a neoplatonist "causally efficacious ethical principle", which he thinks might have been responsible for creating the world and giving physical constants and cosmological parameters the numerical values they have. Derek Parfit (Parfit 1998) considers various "universe selection principles", which although they are very different from what people have traditionally thought of as "God" or a "Designer" can nevertheless suitably be grouped under the heading of design hypotheses for present purposes. We can take "purposeful designer" in a very broad sense to refer to any being, principle or mechanism external to our universe responsible for selecting its properties, or responsible for making it in some sense probable that our universe should be fine-tuned for intelligent life. Needless to say, it is possible to doubt the meaningfulness of many of these design hypotheses. Even if one admits that a given design hypothesis represents a coherent possibility, one may still think that it should be assigned an extremely low degree of credence. For people who are already convinced that there is a God, however, the design hypothesis is apt to appear as an attractive explanation of why our universe is fine-tuned. And if one is not already convinced about the existence of a Designer, but thinks that it is a coherent possibility, one may be tempted to regard fine-tuning as reason for increasing one's credence in that hypothesis. One prominent champion of the fine-tuning argument for God's existence is Richard Swinburne (Swinburne 1991). Several other theologians and philosophers also support this position (see e.g. Craig 1997, Craig 1988, Ross 1992, Polkinghorne 1986, Manson 1989).

The main rival explanation of fine-tuning is the ensemble hypothesis, which states that the universe we observe is only a small part of the totality of physical existence. This totality itself needs not be fine-tuned; if it is sufficiently big and variegated, so that it was likely to contain as a proper part the sort of fine-tuned universe we observe, then an observational selection effect can be invoked to explain why we see a fine-tuned universe. The usual form of the ensemble hypothesis is that our universe is but one in a vast ensemble of actually existing universes, the totality of which we can call "the multiverse", adopting recent terminology. What counts as a universe in such a multiverse is a somewhat vague matter, but "a large, causally fairly disconnected spacetime region" is sufficiently precise for our aims. If the world consists of a sufficiently huge number of such universes, and the values of physical constants vary among these universes according to some suitably broad probability distribution, then it may well be the case that it was quite probable that a fine-tuned universe like ours would come into existence. The actual existence of such a multiverse – an ensemble of "possible universes" would not do – provides the basis on which the observational selection effect operates. The argument then goes like this: Even though the vast majority of the universes are not suitable for intelligent life, it is no wonder that we should observe one of the exceptional universes which are fine-tuned; for the other universes contain no observers and hence are not observed. To observers in such a multiverse, the world will look as if it were fine-tuned. But that is because they see only a small and unrepresentative part of the whole. Observers may marvel at the fact that the universe they find themselves in is so exquisitely balanced, but once they see the bigger picture they can realize that there is really nothing to be astonished by. On the ensemble theory, there *had* to be such a universe (or at least, it was not so improbable that there would be), and since the other universes have no observers in them, a fine-tuned universe is precisely what the observers should expect to observe given the existence of the ensemble. The multiverse itself need not be fine-tuned. It can be robust in the sense that a small change in its basic parameters would not alter the fact that it contains regions where intelligent life exists.

In contrast to some versions of the design hypothesis, the meaningfulness of the ensemble hypothesis is not much in question. Only those subscribing to a very strict verificationist theory of meaning would deny that it is possible that the world might contain a large set of causally fairly disconnected spacetime regions with varying physical parameters. (And even the most hardcore verificationist would be willing to consider at least those ensemble theories according to which other universes are in principle physically accessible from our own universe. Such ensemble theories have been proposed, although they represent only a special case of the general idea.) But there are other philosophical perplexities that arise in this context. One can wonder, for example, in what sense the suggested anthropic explanation of fine-tuning (it is "anthropic" because it involves the idea of an observational selection effect) is really explanatory and how it would relate to a more directly causal account of how our universe came to be. Another important issue is whether fine-tuning provides some evidence for a multiverse. The first question we shall consider, however, is whether fine-tuning stands in any need of explanation at all.

Does fine-tuning need explaining?

First a few words about the supposition that our universe is in fact fine-tuned. This is an empirical assumption which is not entirely trivial. It is certainly true that our current best physical theories, in particular the Grand Unified Theory of the strong, weak, and electromagnetic forces and the big bang theory in cosmology have a number (twenty or so) of free parameters. There is quite strong reason to think at least some of these parameters are fine-tuned – the universe would have been inhospitable to life if their values had been slightly different. (A good overview of the case for fine-tuning is chapter 2 of John Leslie's (Leslie 1989).) While it is true that our knowledge of exotic life forms possible under a different physics than the actual one is very limited (Wilson 1991, Smith 1985, Feinberg and Shapiro 1980), it does seem quite reasonable to think, for instance, that life would not have evolved if the universe had contained only a highly diluted hydrogen gas or if it had recollapsed within a fraction of a second after big bang (referring to the seeming fine-tuning in the early expansion speed) (Leslie 1985). What little direct evidence we have supports this suggestion. Life does not seem to evolve easily even in a universe like our own, which presumably has rather favorable conditions

– complex chemistry, relatively stable environments, large entropy gradients etc. (Hanson 1998, Simpson 1964, Carter 1983, Mayr 1985, Raup 1985, Hart 1982, Papagiannis 1978). There are as yet no signs that life has evolved in the observable universe anywhere outside our own planet (Tipler 1982, Brin 1983).

One should not jump from this to the conclusion that our universe is fine-tuned. For it is possible that some future physical theory will be developed that uses fewer free parameters or uses only parameters on which life does not sensitively depend. However, since the empirical case for fine-tuning is separate from the philosophical problem of how to react if our universe really is fine-tuned, we can set these scruples to one side.[1] Let's assume the most favorable case for fine-tuning enthusiasts: that the physics of our universe has several independent free parameters which are fine-tuned to an extremely high degree. If that is so, is it something that cries out for explanation or should we be happy to accept it as one of those brute facts that just happen to obtain?

I suggest that there are two parts to the answer to this question, one of which is fairly unproblematic. This easier part of the answer is as follows: In general, simplicity is one desideratum on plausible scientific theories. Other things equal, we prefer theories which make a small number of simple assumptions to ones that involve a large number of

[1] If we knew that our universe were not fine-tuned, the issue of what fine-tuning would have implied could still be philosophically interesting. But in fact, the case for fine-tuning is quite strong. Given what we know, it seems reasonable to doubt that there is a plausible physical theory on which our universe is not fine-tuned. Inflation theory, which was originally motivated largely by a desire to avoid the fine-tuning regarding the flatness and smoothness of the universe required by the ordinary big bang theory, seems to require some fine-tuning of its own to get the inflation potential right. More recent inflation theories may overcome this problem, at least partly; but they do so by introducing a multiverse and an observational selection effect – in other words by doing exactly the sort of thing that this paper will scrutinize. The present best candidate for a single-universe theory that could reduce the number of free parameters may be superstring theories, but they too seem to require at least some fine-tuning (because there are many possible compactification schemes and vacuum states). The theories that currently seem most likely to be able to do away with fine-tuned free parameters all imply the existence of a multiverse. On these theories, *our* universe might still be fine-tuned although the multiverse as a whole might not be, or might be fine-tuned only to a less degree.

ad hoc stipulations. I see no reason not to apply this methodological principle in cosmology. It is used successfully in the rest of science and indeed has a strong track record within cosmology too.[2] Thus, I think one can admit that there is something dissatisfactory about a cosmological theory which tells us that the universe contains a large number of fine-tuned constants. Such a theory might be true, but we should not be keen to believe that until we have convinced ourselves that there is no simpler theory that can account for the data we have. So if the universe looks fine-tuned, this can be an indication that we should look harder to see if we cannot find a theory which reduces the number of independent assumptions needed. This is one reason for why a universe that looks fine-tuned (whether or not it actually *is* fine-tuned) is crying out for explanation.

We should note two things about this easy part of the answer. First, there might not be an explanation even if the universe is "crying out" for one in this sense. There is no guarantee that there is a simpler theory using fewer free parameters which can account for the data. At most, there is a prima facie case for looking for one, and for preferring the simpler theory if one can be found.

Second, the connection to fine-tuning is merely incidental. In this part of the answer, it is not fine-tuning *per se*, only fine-tuning to the extent that it is coupled to having a wide range of free parameters, that is instigating the search for a better explanation. Fine-tuning is neither necessary nor sufficient for this. It is not sufficient, because in order for a theory to be fine-tuned for intelligent life, it needs to have but a single free parameter. If a theory has a single physical constant on which the existence of intelligent life very sensitively depends, then the theory is fine-tuned. Yet a theory with only one free parameter could be eminently simple. If a universe cries out for explanation

[2] For example, think of the replacement of the complicated Ptolomaic theory of planetary motion by the far simpler Keplerian theory. Some people might regard Einstein's relativity theory as more complicated than Newton's theory of gravitation (although "more difficult" seems a more accurate description in this case than "more complicated"). But note that the *ceteris paribus* includes the presupposition that the two theories predict known data equally well, so this would not be a counterexample. Newton's theory does not fit the evidence.

even though such a theory accounts for all available evidence, it must clearly be on some other basis than that of a general preference for simpler theories. Also, fine-tuning is not necessary for there to be a cry for explanation. One can imagine a cosmological theory which contains a large number of free parameters but is not fine-tuned because life does not sensitively depend on the values assigned to these parameters.

The easy part of the answer is therefore: Yes, fine-tuning cries out for explanation to the extent to which it is correlated with an excess of free parameters and a resultant lack of simplicity.[3] This part of the answer has been overlooked in discussions of fine-tuning, yet it is important to separate out this aspect in order to rightly grasp the more problematic part to which we shall now turn. The problematic part is to address the question of whether fine-tuning *especially* cries out for explanation, beyond the general desideratum of avoiding unnecessary complications and ad hoc assumptions. In other words, is *the fact that the universe would have been lifeless* if the values of fundamental constants had been very slightly different (assuming this is a fact) relevant in assessing whether an explanation is called for of why the constants have the values they have? And does it give support to the multiverse hypothesis? Or alternatively to the design hypothesis? The rest of this paper will focus on these questions (though the design hypothesis will be discussed only as it touches on the other two questions).

[3] The simplicity principle I'm using here is not that every phenomenon must have an explanation (which would be version of the principle of sufficient reason, which I do not accept). Rather, what I mean is that we have an a priori epistemic bias in favor of hypotheses which are compatible with us living in a relatively simple world. Therefore, if our best account so far of some phenomenon involves very non-simple hypotheses (such as that a highly remarkable coincidence happened just by chance), then we may have prima facie reason for thinking that there is some better (simpler) explanation of the phenomenon that we haven't yet thought of. In that sense, the phenomenon is crying out for an explanation. Of course, there might not be a (simple) explanation. But we shouldn't be willing to believe in the complicated account until we have convinced ourselves that no simple explanation would work.

Ian Hacking and the Inverse Gambler's Fallacy

Can an anthropic argument based on an observational selection effect together with the assumption that an ensemble of universes exists explain the apparent fine-tuning of our universe? Ian Hacking has argued that this depends on the nature of the ensemble. If the ensemble consists of all possible big-bang universes (a position he ascribes to Brandon Carter) then, says Hacking, the anthropic explanation works:

> Why do we exist? Because we are a possible universe [sic], and all possible ones exist. Why are we in an orderly universe? Because the only universes that we could observe are orderly ones that support our form of life. …nothing is left to chance. Everything in this reasoning is deductive. (Hacking 1987, p. 337)

Hacking contrasts this with a seemingly analogous explanation which seeks to explain fine-tuning by supposing that a Wheeler-type multiverse exists. In the Wheeler cosmology, there is a never-ending sequence of universes each of which begins with a big bang and ends with a big crunch which bounces back in a new big bang, and so forth. The values of physical constants are reset in a random fashion in each bounce, so that we have a vast ensemble of universes with varying properties. The purported anthropic explanation of fine-tuning based on such a Wheeler ensemble notes that given that the ensemble is large enough then it could be expected to contain at least one fine-tuned universe like ours. An observational selection effect can be invoked to explain why we observe a fine-tuned universe rather than one of the non-tuned ones. On the face of it, this line of reasoning looks very similar to the anthropic reasoning based on the Carter multiverse, of which Hacking approves. But according to Hacking, there is a crucial difference. He thinks that the version using the Wheeler multiverse commits what he dubs the "Inverse Gambler's Fallacy". This is the fallacy of a dim-witted gambler who thinks that the apparently improbable outcome he currently observes is made more probable if there have been many trials preceding the present one.

> [A gambler] enters the room as a roll is about to be made. The kibitzer asks, 'Is this the first role of the dice, do you think, or have we made many a one earlier tonight?… slyly, he says 'Can I wait until I see how this roll comes out, before I lay my bet with you on the number of past plays made tonight?' The kibitzer… agrees. The roll is a double six. The gambler foolishly says, 'Ha, that makes a difference – I think there have been quite a few rolls.' (Hacking 1987, p. 333)

The gambler in this example is clearly making a mistake. But it is almost equally clear that Hacking is making a mistake in thinking that the situation is analogous to the one regarding fine-tuning. As was pointed out by three independent authors (Whitaker 1988, McGrath 1988, Leslie 1988) replying to Hacking's paper, there is no observational selection effect in his example – an essential ingredient in the purported anthropic explanation of fine-tuning.

One way of introducing an observational selection effect in Hacking's example is by supposing that the gambler has to wait outside the room until a double six is rolled. Knowing that this is the setup, the gambler does obtain some reason upon entering the room and seeing the double six for thinking that there have probably been quite a few rolls already. This is a closer analogy to the fine-tuning case. The gambler can only observe certain outcomes – we can think of these as the "fine-tuned" ones – and upon observing a fine-tuned outcome he obtains reason to think that there have been several trials. Observing a double six would be surprising on the hypothesis that there were only one roll, but it would be expected on the hypothesis that there were very many. Moreover, a kind of explanation of why the gambler is seeing a double six is provided by pointing out that there were many rolls and the gambler would be let in to observe the outcome only upon rolling a double six. When we make the example more similar to the fine-tuning situation, we find that it supports, rather than refutes, the analogous reasoning based on the Wheeler cosmology.

What makes Hacking's position especially peculiar is that he thinks that the anthropic reasoning works with a Carter multiverse but not in a Wheeler universe. Every author I am aware of who has written about this thinks that Hacking is wrong on this point. Many think the anthropic reasoning works in both cases, some think it doesn't work in either case, but Hacking is probably alone in thinking it works in one but not the other. The only pertinent difference between the two cases seems to be that in the Carter case one *deduces* the existence of a universe like ours, whereas in the Wheeler case one infers it probabilistically. The Wheeler case can be made to approximate the Carter case by having the probability that a universe like ours should be generated in some cycle be close to 1. (This is in fact the case in the Wheeler scenario if there are infinitely many cycles and there is a fixed finite probability in each cycle of a universe like ours resulting). It is hard to see the appeal of a doctrine that drives a methodological wedge between the two cases, asserting that the anthropic explanation works perfectly in one and works not at all in the other.

Robert White and Phil Dowe's analysis

A more challenging attack on the anthropic explanation of fine-tuning has recently been made by Robert White (White 2000) and Phil Dowe (Dowe 1998). They eschew Hacking's doctrine that there is an essential difference between the Wheeler and the Carter multiverse as regards the correctness of corresponding anthropic fine-tuning explanation. But they take up another idea of Hacking's, namely that what goes wrong in the Inverse Gambler's Fallacy is that the gambler fails to regard the most specific version he knows of the explanandum when making his inference to the best explanation. If all the gambler had known were that *a* double six had been rolled, then it need not have been a fallacy to infer that there probably were quite a few rolls (since that would have made it more probable that there would be at least one double six). However, the gambler knows that *this* roll – the latest one – was a double six, and this gives him no reason to believe there were many rolls (since the probability that that roll would be a double six is one in thirty-six independently of how many times the dice have been rolled). And, argues Hacking, we have to use the most specific explanandum that we have knowledge of:

> If F is known, and E is the best explanation of F, then we are supposed to infer E. However, we cannot give this rule *carte blanche*. If F is known, then FvG is known, but E* might be the best explanation of FvG, and yet knowledge of F gives not the slightest reason to believe E*. (John, an excellent swimmer, drowns in Lake Ontario. Therefore he drowns in either Lake Ontario or the Gulf of Mexico. At the time of his death, a hurricane is ravaging the Gulf. So the best explanation of why he drowned is that he was overtaken by a hurricane, which is absurd.) We must insist that F, the fact to be explained, is the most specific version of what is known and not a disjunctive consequence of what is known. (Hacking 1987, p. 335)

Applying this to fine-tuning, Hacking, White and Dowe charge that the purported anthropic explanation of fine-tuning fails to explain the most specific version of what is known. We know not only that *some* universe is fine-tuned; we know that *this* universe is fine-tuned. Now, if our explanandum is, Why is *this* universe fine-tuned? – where “this universe” is understood rigidly –, it would seem that postulating many universes would not go anywhere towards explaining this; nor would it make the explanandum more probable. For how could the existence of many other universes make it more likely that this universe would be fine-tuned?

It is useful at this stage to introduce some abbreviations. In order to focus on the point that White and Dowe are making, we can make some simplifying assumptions.[4] Let us suppose that there are n possible configurations of a big bang universe $\{T_1, T_2, \ldots, T_n\}$ and that they are equally "probable", $P(T_i) = 1/n$. We assume that T_1 is the only configuration that permits life to evolve. Let the variable "x" range over the set of actual universes. We assume that each universe instantiates a unique T_i, so that $\forall x \exists ! i (T_i x)$. Let $m \leq n$ be the number of actually existing universes, and let "α" rigidly denote our universe. We define

$E := T_1 \alpha$ ("α is life-permitting.")

$E' := \exists x (T_1 x)$ ("Some universe is life-permitting.")

$M := m >> 0$ ("There are many universes." – the multiverse hypothesis)

White claims that while there being many universes increases the probability that there is a life-permitting universe, $P(E'|M) > P(E'|\neg M)$, it is not the case that there being many universes increases the probability that our universe is life-permitting. That is, $P(E|M) = P(E|\neg M) = 1/n$. The argument White gives for this is that

> the probability of [E, i.e. the claim that α instantiates T_1] is just $1/n$, regardless of how many other universes there are, since α's initial conditions and constants are selected randomly from a set of n equally probable alternatives, a selection which is independent of the existence of other universes. The events which give rise to universes are not causally related in such a way that the outcome of one renders the outcome of another more or less probable. They are like independent rolls of a die. (White 2000, pp.262-3)

[4] I will adopt White's formalism to facilitate comparison. The simplifying assumptions are also made by White, on whose analysis we focus since it is more detailed than Dowe's.

Since we should conditionalize on the most specific information we have when evaluating the support for the multiverse hypothesis, and since E' is more specific than E, White concludes that our knowledge that our universe permits life to evolve gives us no reason to think there are many universes.

This argument has some initial plausibility. Nonetheless, I think it is fallacious. We get a hint that something has gone wrong if we pay attention to a certain symmetry of the situation. Let α, β_1, …, β_{n-1} be the actually existing universes, and for $i = \alpha$, β_1, …, β_{n-1}, let E_i be the proposition that if some universe is life-permitting then *i* is life-permitting. Thus, E is equivalent to the conjunction of E' and E_α. According to White, P(M|E') > P(M) and P(M|E' E_α) = P(M|E) = P(M), which implies P(M|E' E_α) < P(M|E'). Because of the symmetry of the β_j:s, P(M|E' $E_{\beta j}$) = *c*, for every β_j. This entails that P(M|E' $E_{\beta j}$) < P(M|E') for every β_j. In other words, White is committed to the view that, given that some universe is life-permitting, then conditionalizing on α being life-permitting decreases the probability of M, while conditionalizing on any of β_1, …, β_{n-1} increases the probability of M. But this seems wrong. Given that some universe is life-permitting, why should the fact it is *this* universe that is life-permitting, rather than any of the others, lower the probability that there are many universes? If it had been some other universe instead of this one that had been life-permitting, why should that have made the multiverse hypothesis any more likely? Clearly, such discrimination could be justified only if there were something special that we knew about *this* universe that would make the fact that it is this universe rather than some other that is life-permitting significant. I can't see what sort of knowledge that would be. It is true that *we* are in this universe and not in any other – but that fact *presupposes* that it is life-permitting. It is not as if there is a remarkable coincidence between our universe being life-permitting and us being in it. So it's hard to see how the fact that we are in this universe could justify treating its being life-permitting as giving a lower probability to the multiverse hypothesis than any other universe's being life-permitting would have.

So what, precisely, is wrong in White's argument? His basic intuition for why P(M|E) = P(M) seems to be that "The events which give rise to universes are not causally related in such a way that the outcome of one renders the outcome of another more or less probable.". But a little reflection reveals that this statement it is highly problematic for several reasons.

First, there is no current warrant for making the assertion. Very little is still known about the events which give rise to universes. There are models on which the outcomes of some such events causally influence the outcome of others. To illustrate, in Lee Smolin's (admittedly highly speculative) evolutionary cosmological model (Smolin 1997), universes create "baby-universes" whenever a black hole is formed, and these baby-universes inherit some of the properties of their parents. The outcomes of chance events in one such conception can thus influence the outcomes of chance events in the births of other universes. Variations of the Wheeler oscillating universe model have also been suggested where some properties are inherited from one cycle to the next. Andrei Linde has speculated about the possibility that advanced civilizations may have the ability to create "basement-universes" and transfer some information into them.

Even if the events which give rise to universes are not causally related in the sense that the outcome of one event causally influences the outcome of another (as in the above examples), that does not mean that one universe may not carry information about another. For instance, two universes can have a partial cause in common. This is the case in the multiverse models associated with inflation theory (arguably the best current candidates for a multiverse cosmology). In a nutshell, the idea is that universes arise from inflating fluctuations in some background space. The existence of this background space and the parameters of the chance mechanism which lead to the creation of inflating bubbles are at least partial causes of the universes that are produced. The properties of the produced universes could thus carry information about this background space and the mechanism of bubble creation, and hence indirectly also about other universes that have been produced by the same mechanism. The majority of multiverse models that have actually been proposed, including arguably the most plausible one, thus negate White's categorical statement.

Second, we can consider the hypothetical case of a multiverse model where the universes bear no causal relations to one another. But even there, it is not clear that that P(M|E) = P(M). We need to make a distinction between objective chance and epistemic probability. If there is no causal connection (whether direct or indirect) between the universes, then there is no correlation in the physical chances of the outcomes of the events in which these universes are created. It doesn't follow that the outcomes of those events are uncorrelated in one's epistemic probability assignment. Consider this toy example:

> Suppose you have some background knowledge K and that your prior subjective probability function P, conditionalized on K, assigns non-negligible probability to only three possible worlds and assigns an equal probability to these: $P(w_1|K) = P(w_2|K) = P(w_3|K) \approx 1/3$. In w_1 there is one big universe, *a*, and one small universe, *d*; in w_2 there is one big, *b*, and one small, *e*; and in w_3 there is one big, *c*, and one small, *e*. Now suppose you learn that you are in universe *e*. This rules out w_1. It thus gives you information about the big universe – it is now more likely to be either *b* or *c* than it was before you learnt that the little universe is *e*. That is, P("The big universe is *b* or *c*"|K&"The little universe is *e*") > P("The big universe is *b* or *c*"|K).

No assumption is made here about the universes being causally related. White presupposes that there is no such subjective probability function P, or that such a probability function must be irrational or unreasonable (independently of the exact nature of the various possible worlds under consideration). But that seems an implausible assumption, and no argument for it is provided.

Third, White's view that P(M|E') > P(M) seems to commit him to denying this assumption. For how could E' (which says that some universe is life-permitting) be probabilistically relevant to M unless the outcome of one universe-creating event *x* (namely that event, or one of those events, that created the life-permitting universe(s)) can be probabilistically relevant to the outcome of another *y* (namely one of those events that created the universes other than *x*)? If *x* gives absolutely no information about *y*, then there is no reason to think that because *x* resulted in a life-permitting universe, so did quite probably *y* too. So on this reasoning, we would have P(M|E') = P(M). (This point connects back to the initial observation regarding the symmetry and the implausibility of thinking that because it is *our* universe that is life-permitting this gives less support for the multiverse hypothesis than if it had been some other universe instead that were life-permitting.)

I conclude that White's argument against the view that fine-tuning lends some support to the multiverse hypothesis fails, and so do consequently Phil Dowe's and Ian Hacking's (the latter failing on additional grounds as well, as described in the preceding section).

Surprising vs. unsurprising improbable events

If, then, the fact that our universe is life-permitting *does* give support to the multiverse hypothesis, i.e. P(M|E) > P(M), it follows from Bayes's theorem that P(E|M) > P(E). How can the existence of a multiverse make it more probable that *this* universe should be life-permitting? One may be tempted to say: By making it more likely that this universe should exist. The problem with this reply is that it would seem to equally validate the inference to many universes from any sort of universe whatever. For instance, let E* be the proposition that α is a universe that contains nothing but chaotic light rays. It seems wrong to think that P(M|E*) > P(M). Yet, if the only reason that P(E|M) > P(E) is that α

is more likely to exist if M is true, then an exactly analogous reason would support P(E*|M) > P(E*), and hence P(M|E*) > P(M). This presents the anthropic theorizer with a puzzle.

Several prominent supporters of the anthropic argument for the multiverse hypothesis have sought to ground their argument in a distinction between events (or facts) that are surprising and those that are improbable but not surprising (e.g. John Leslie (Leslie 1989) and Peter van Inwagen (van Inwagen 1993)).[5] Suppose you toss a coin one hundred times and write down the results. Any particular sequence *s* is highly improbable ($P(s) = 2^{-100}$), yet most sequences are not surprising. If *s* contains roughly equally many heads and tails, and no clear pattern, then *s* is improbable and unsurprising. By contrast, if *s* consists of 100 heads, or of alternating heads and tails, or some other highly patterned outcome, then *s* is surprising. Or to take another example, if *x* wins a lottery with one billion tickets, this is said to be unsurprising ("someone had to win, it could just as well be *x* as anybody else. shrug."); whereas if there are three lotteries with a thousand tickets each, and *x* wins all three of them, this is surprising. We evidently have some intuitive concept of what it is for an outcome to be surprising in cases like these.

[5] Some authors who are skeptical about the claim that fine-tuning is evidence for a multiverse still see a potential role of an anthropic explanation using the multiverse hypothesis as a way of reducing the surprisingness or amazingness of the observed fine-tuning. A good example of this tack is John Earman's paper on the anthropic principle (Earman 1987), in which he criticizes a number of illegitimate claims made on behalf of the anthropic principle by various authors (especially concerning those misnamed "anthropic principles" that don't involve any observational selection effects and hence bear little or no relation to Brandon Carter's original ideas on the topic (Carter 1974; Carter 1983; Carter 1989; Carter 1990)). But in the conclusion he writes: "There remains a potentially legitimate use of anthropic reasoning to alleviate the state of puzzlement into which some people have managed to work themselves over various features of the observable portion of our universe. … But to be legitimate, the anthropic reasoning must be backed by substantive reasons for believing in the required [multiverse] structure." (p. 316). Similar views are espoused by Ernan McMullin (McMullin 1993), Bernulf Karnitscheider (Kanitscheider 1993), and (less explicitly) by George Gale (Gale 1996). I agree that anthropic reasoning reduces puzzlement only given the existence of a suitable multiverse, but I disagree with the claim that the potential reduction of puzzlement is no ground whatever for thinking that the multiverse hypothesis is true. My reasons for this will become clear as we proceed.

The idea, then, is that a fine-tuned universe is surprising in a sense in which a particular universe filled with only chaotic electromagnetic radiation would not have been. And that's why we need to look for an explanation of fine-tuning but would not have had any reason to suppose there were an explanation for a light-filled universe. The two potential explanations for fine-tuning that typically are considered are the design hypothesis and the multiple universe hypothesis. An inference is then made that at least one of these hypotheses is quite likely true in light of available data, or at least more likely true than would have been the case if this universe had been a "boring" one containing only chaotic light. This is similar to the 100 coin flips example: an unsurprising outcome does not lead us to search for an explanation, while a run of 100 heads does cry out for explanation and gives at least some support to potential explanations such as the hypothesis that the coin flipping process was biased. Likewise in the lottery example. The same person winning the all three lotteries could make us suspect that the lottery had been rigged in the winner's favor, especially if there were some independent evidence for this.

A key assumption in this argument is that fine-tuning is indeed surprising. Is it? Some dismiss the possibility out of hand. For example, Stephen Jay Gould writes:

> Any complex historical outcome – intelligent life on earth, for example – represents a summation of improbabilities and becomes therefore absurdly unlikely. But something has to happen, even if any particular "something" must stun us by its improbability. We could look at any outcome and say, "Ain't it amazing. If the laws of nature had been set up a tad differently, we wouldn't have this kind of universe at all." (Gould 1990, p. 183)

Peter van Inwagen mocks that way of thinking:

> Some philosophers have argued that there is nothing in the fact that the universe is fine-tuned that should be the occasion for any surprise. After all (the objection runs), if a machine has dials, the dials have to be set *some* way, and any particular setting is as unlikely as any other. Since any setting of the dial is as unlikely as any other, there can be nothing more surprising about the actual setting of the dials, whatever it may be, than there would be about any possible setting of the dials if that possible setting were the actual setting. … This reasoning is sometimes combined with the point that if "our" numbers hadn't been set into the cosmic dials, the equally improbable setting that did occur would have differed from the actual setting mainly in that there would have been no one there to wonder at its improbability. (van Inwagen 1993, pp. 134-5)

Opining that this "must be one of the most annoyingly obtuse arguments in the history of philosophy", van Inwagen asks us to consider the following analogy. Suppose you have to draw a straw from a bundle of 1,048,576 straws of different lengths. It has been decreed that unless you draw the shortest straw you will be instantly killed so that you don't have time to realize that you didn't draw the shortest straw. "Reluctantly – but you have no alternative – you draw a straw and are astonished to find yourself alive and holding the shortest straw. What should you conclude?" According to van Inwagen, only one conclusion is reasonable: that you did not draw the straw at random but that instead the situation was somehow rigged by an unknown benefactor to ensure that you got the shortest straw. The following argument to the contrary is dismissed as "silly":

> Look, you had to draw some straw or other. Drawing the shortest was no more unlikely than drawing the 256,057th-shortest: the probability in either case was .000000954. But your drawing the 256,057th-shortest straw isn't an outcome that would suggest a 'set-up' or would suggest the need for any sort of explanation, and, therefore, drawing the shortest shouldn't suggest the need for an explanation

> either. The only real difference between the two cases is that you wouldn't have been around to remark on the unlikelihood of drawing the 256,057th-shortest straw. (van Inwagen 1993, p. 135)

Given that the rigging hypothesis did not have too low a prior probability and given that there was only one straw lottery, it is hard to deny that this argument would indeed be silly. What we need to reflect about, though, is whether the example is analogous to our epistemic situation regarding fine-tuning.

Erik Carlson and Erik Olsson (Carlson and Olsson 1998), criticizing van Inwagen's argument, argue that there are three points of disanalogy between van Inwagen's straw lottery and fine-tuning. First, they note that whether we would be willing to accept the "unknown benefactor" explanation after drawing the shortest straw depends on our prior probability of there being an unknown benefactor with the means to rig the lottery. If the prior probability is sufficiently tiny – given certain background beliefs it may be very hard to see how the straw lottery *could* be rigged – we would not end up believing in the unknown benefactor hypothesis. Obviously, the same applies to the fine-tuning argument: if the prior probability of a multiverse is small enough then we won't accept that hypothesis even after discovering a high degree of fine-tuning in our universe. I think the multiverse supporter can grant this and argue that the prior probability of a multiverse is not too small. Exactly how small it can be for us still to end up accepting the multiverse hypothesis depends on both how extreme the fine-tuning is and what alternative explanations are available. If there is plenty of fine-tuning, and the only alternative explanation on the table is the design hypothesis, and if that hypothesis is assigned a much lower prior probability than the multiverse hypothesis, then the argument for the multiverse hypothesis would be vindicated. We don't need to commit ourselves to these assumptions; and in any case, different people might have different prior probabilities. What we are primarily concerned with here is to determine whether fine-tuning is in a relevant sense a *surprising* improbable event, and whether taking fine-tuning into account should substantially *increase* our credence in the multiverse hypothesis and/or the design hypothesis, not what the absolute magnitude of our credence in those hypotheses should be. Carlson and Olsson's first point is granted but it doesn't have any bite. van Inwagen never claimed that his straw lottery example could settle the question of what the prior probabilities should be.

Carlson and Olsson's second point would be more damaging for van Inwagen, if it weren't incorrect. They claim that there is a fundamental disanalogy in that we understand at least roughly what the causal mechanisms are by which intelligent life evolved from inorganic matter whereas no such knowledge is assumed regarding the causal chain of events that led you to draw the shortest straw. To make the lottery more closely analogous to the fine-tuning, we should therefore add to the description of the lottery example that at least the proximate causes of your drawing the shortest straw are known. Carlson and Olsson then note that:

> In such a straw lottery, our intuitive reluctance to accept the single-drawing-plus-chance hypothesis is, we think, considerably diminished. Suppose that we can give a detailed causal explanation of why you drew the shortest straw, starting from the state of the world twenty-four hours before the drawing. A crucial link in this explanation is the fact that you had exactly two pints of Guinness on the night before the lottery. … Would you, in light of this explanation of your drawing the shortest straw, conclude that, unless there have been a great many straw lotteries, somebody intentionally caused you to drink two pints of Guinness in order to ensure that you draw the shortest straw? … To us, this conclusion does not seem very reasonable. (Carlson and Olsson 1998, pp. 271-2)

The objection strikes me as unfair. Obviously, if you knew that your choosing the shortest straw depended crucially and sensitively on your precise choice of beverage the night before, you would feel disinclined to accept the rigging hypothesis. That much is right. But this disinclination is fully accounted for by the fact that it is tremendously hard to see, under such circumstances, how anybody *could* have rigged the lottery. If we knew that successful rigging required predicting in detail such a long and tenuous causal chain of events, we could well conclude that the prior probability of rigging was negligible. For *that* reason, surviving the lottery would not make us believe the rigging hypothesis. We can see that it is this – rather than our understanding of the proximate causes per se – that defeats the argument for rigging, by considering the following variant of van Inwagen's example. Suppose that the straws are scattered over a vast area. Each straw has one railway track leading up to it, all the tracks starting from the same station. When you pick the shortest straw, we now have a causal explanation that can stretch far back in time: you picked it because it was at the destination point of a long journey along a track that did not branch. How long the track was makes no difference to how willing we are to believe in the rigging hypothesis. What matters is only whether we think there is some plausibility to the idea that an unknown benefactor could have put you on the right track to begin with. So contrary to what Carlson and Olsson imply, what is relevant is not the known backward length of the causal chain, but whether that chain would have been sufficiently predictable by the hypothetical benefactor to give a sufficient prior probability to the hypothesis that she rigged the lottery. Needless to say, the designer referred to in the design hypothesis is typically assumed to have superhuman epistemic capacities. It is not at all farfetched to suppose that *if* there were a cosmic designer, she would have been able to anticipate which boundary conditions of the universe were likely to lead to the evolution of life. We should therefore reject Carlson and Olsson's second objection against van Inwagen's analogy.

The third alleged point of disanalogy is somewhat subtler. Carlson and Olsson discuss it in the context of refuting certain claims by Arnold Zuboff (Zuboff 1991) and it is not clear how much weight they place on it as an objection against van Inwagen. It's nonetheless worth mentioning. The idea, so far as I can make it out, is that the reason why your existing after the straw lottery is surprising, is related to the fact that you existed before the straw lottery. You could have antecedently contemplated your survival as one of a variety of possible outcomes. In the case of fine-tuning, by contrast, your existing (or intelligent life existing) is not an outcome which could have been contemplated prior to its obtaining.

> For conceptual reasons, it is impossible that you know in advance that your existence lottery is going to take place. Likewise, it is conceptually impossible that you make any *ex ante* specification of any possible outcome of this lottery. … The existence of a cosmos suitable for life does not seem to be a coincidence for anybody; nobody was ever able to specify this outcome of the cosmos lottery, independently of its actually being the actual outcome. (Carlson and Olsson 1998, p. 268)

This might look like a token of the "annoyingly obtuse" reasoning that van Inwagen thought to refute through his straw lottery example. Nevertheless, there is a disanalogy between the two cases: nobody could have contemplated the existence of intelligent life unless intelligent life existed, whereas someone (even the person immediately involved) could have thought about drawing the shortest straw before drawing it. But the question is whether this difference is relevant. Again it is useful to cook up a variant of van Inwagen's example:

> Suppose that in an otherwise lifeless universe there is a big bunch of straws and a simple (non-cognitive, non-conscious) automaton is about to randomly select one of the straws. There is also kind of "incubator" in which one person rests in an unconscious state; we can suppose she has been unconscious since the beginning of time. The automaton is set up in such a way that the person in the incubator will be woken if and only if the automaton picks the shortest straw. You wake up in the incubator. After examining your surroundings and learning about how the

> experiment was set up, you begin to wonder about whether there were anything surprising about the fact that the shortest straw was drawn.

This example shares with the fine-tuning case the feature that nobody would have been there to contemplate anything if the "special" outcome had failed to obtain. So what should we say about this case? In order for Carlson and Olsson's criticism to work, we would have to say that the person waking up in the incubator should not think that there is anything surprising at all about the shortest straw having been selected. van Inwagen would most probably simply deny that that would be the correct attitude. For what it's worth, my intuition in this instance sides with Inwagen, although this case is perhaps less obvious than van Inwagen's original straw lottery where the subject had a life before the lottery.

It would be nice to have an independent account of what makes an event or a fact surprising. We could then apply the general account to the straw lotteries or directly to fine-tuning, and see what follows. Let us therefore briefly review what efforts have been made to develop such an account of surprisingness. To anticipate the upshot: I will argue that these represent a dead end so far as anthropic reasoning is concerned. From this we will learn that the strategy of anthropic theorizers who base their case on an appeal to what is surprising is ultimately of very limited utility: the strategy is grounded on intuitions that are not any more obvious or secure than the thesis which they are employed to support. This may seem disappointing, but in fact it clears the path for a better understanding what is required to support anthropic reasoning.

The following remark by F. P. Ramsey is pertinent to the goal of determining what distinguishes surprising improbable events from unsurprising improbable events:

> What we mean by an event not being a coincidence, or not being due to chance, is that if we came to know it, it would make us no longer regard our system as satisfactory, although on our system the event may be no more improbable than

> any alternative. Thus 1,000 heads running would not be due to chance; i.e. if we observed it we should change our system of chances for that penny. (Ramsey 1990, p. 106)

This looks like promising beginning. It seems to fit the other example considered near the beginning of this section: one person winning three lotteries with a thousand tickets could make us suspect foul play, whereas one person winning a billion-ticket lottery would not in general have any tendency do so. Or ponder the case of a monkey typing out the sequence "Give me a banana!". This is surprising and it makes us change our belief that the monkey types out a random sequence. We would think that maybe the monkey had been trained to type that specific sequence, or maybe that the typewriter was rigged; but the chance hypothesis is disconfirmed. By contrast, if the monkey types out "r78o479024io; jl;", this is unsurprising and does not challenge our assumptions about the setup. So far so good.

What Ramsey's suggestion does not tell us what it is about events such as the monkey's typing a meaningful sentence or the run of 1000 heads that makes us change our mind about the system of chances. We need to know that if the suggestion is to throw any light on the fine-tuning case. For the problem there is precisely that it is not immediately clear – lest the question be begged – whether we ought to change our system and find some alternative explanation or be satisfied with letting chance pay the bill, that is, in Ramsey's terminology, regarding fine-tuning as a coincidence. Ramsey's suggestion is thus insufficient for the present purpose.

Paul Horwich takes the analysis further. He proposes the following as a necessary condition for the truth of a statement E being surprising:

> [T]he truth of E is surprising only if the supposed circumstances C, which made E seem improbable, are themselves substantially diminished in probability by the truth of E…and if there is some initially implausible (but not widely implausible)

> alternative view K about the circumstances, relative to which E would be highly probable. (Horwich 1982, p. 101)

If we combine this with the condition that "our beliefs C are such as to give rise to $P(E) \approx 0$", we get what Horwich thinks is a necessary and sufficient condition for the truth of a statement being surprising. We can sum this up by saying that the truth of E is surprising iff the following holds:

(i) $P(E) \approx 0$

(ii) $P(C|E) << P(C)$

(iii) $P(E|K) \approx 1$

(iv) $P(K)$ is small but not too small

Several authors who think that fine-tuning cries out for explanation endorse views that are similar to Horwich's (Manson 1989). For instance, Peter van Inwagen writes:

> Suppose there is a certain fact that has no known explanation; suppose that one can think of a possible explanation of that fact, an explanation that (if only it were true) would be a very *good* explanation; then it is wrong to say that that event stands in no more need of an explanation than an otherwise similar event for which no such explanation is available. (van Inwagen 1993, p. 135)

And John Leslie:

> A chief (or the only?) reason for thinking that something stands in [special need for explanation], i.e. for justifiable reluctance to dismiss it as how things just

> happen to be, is that one in fact glimpses some tidy way in which it might be explained. (Leslie 1989, p. 10)

D. J. Bartholomew also appears to support a similar principle (Bartholomew 1984). Horwich's analysis provides a reasonably good explication of these ideas.

George Schlesinger (Schlesinger 1991) has criticized Horwich's analysis, arguing that the availability of a tidy explanation is not necessary for an event being surprising. Schlesinger asks us to consider the case of a tornado that touches down in three different places, destroying one house in each place. We are surprised to learn that these houses belonged to the same person and that they are the only buildings that this misfortunate capitalist owned. Yet no neat explanation suggests itself. Indeed, it seems to be *because* we can see no tidy explanation (other than the chance hypothesis) that this phenomenon would be so surprising. So if we let E to be the event that the tornado destroys the only three buildings that some person owns and destroys nothing else, and C the chance hypothesis, then (ii) - (iv) are not satisfied. According to Horwich's analysis, E is not surprising – which is counterintuitive.

Surprise being ultimately a psychological matter, we should perhaps not expect any simple definition to perfectly capture all the cases where we would feel surprised. But maybe Horwich has provided at least a sufficient condition for when we ought to feel surprised? Let's run with this for a second and see what happens when we apply his analysis to fine-tuning. In order to do this we need to determine the probabilities referred to in (i)-(iv). Let's grant that the prior probability of fine-tuning (E) is very small, $P(E) \approx 0$. Further, anthropic theorizers maintain that E makes the chance hypothesis substantially less probable than it would have been without conditionalizing E, so let's suppose that $P(C|E) << P(C)$[6]. Let K be a multiverse hypothesis. In order to have

[6] This follows from Bayes's theorem if the probability that C gives to E is so tiny that $P(E|C) << P(E)$.

$P(E|K) \approx 1$, it might be necessary to think of K as more specific than the proposition that there is some multiverse; we may have to define K as the proposition that there is a "suitable" multiverse (i.e. one such that $P(E|K) \approx 1$ is satisfied). But let us suppose that even such a strengthened multiverse hypothesis has a prior probability that is not "too small". If we make these assumptions then Horwich's four conditions are satisfied, and the truth of E would consequently be surprising. This is the result that the anthropic theorizer would like to see.

Unfortunately, we can construct a similar line of assumptions to show that any other possible universe would have been equally surprising. Let $E^{\#}$ be the proposition that α has some particular boring character. For instance, we can let $E^{\#}$ say that α is a universe which consists of nothing but such-and-such a pattern of electromagnetic radiation. We then have $P(E^{\#}) \approx 0$. We can let K be the same as before. Now, if we suppose that $P(C|E^{\#}) << P(C)$ and $P(E^{\#}|K) \approx 1$ then the truth of $E^{\#}$ will be classified as surprising. This is counterintuitive, and if it were true that every possible universe would be just as surprising as any other then fine-tuning being surprising can surely not be what legitimizes the inference from fine-tuning to the multiverse hypothesis. We must therefore deny either $P(C|E^{\#}) << P(C)$ or $P(E^{\#}|K) \approx 1$ (or both). At the same time, if the truth of E is to be surprising, we must maintain that $P(C|E) << P(C)$ and $P(E|K) \approx 1$. This means that the anthropic theorizer wishing to ground her argument in an appeal to surprise must treat $E^{\#}$ differently from E as regards these conditional probabilities. It may be indeed be correct to do that. But what is the justification? Whatever is it, it cannot be that the truth of E is surprising whereas the truth of $E^{\#}$ is not. For although that might be true, to simply assume that would be to make the argument circular.

The appeal to the surprisingness of E is therefore quite ineffective. In order to give the appeal any force, it needs to be backed up by some argument for the claim that:

$P(C|E) << P(C)$, $P(E|K) \approx 1$ but not both $P(C|E^{\#}) << P(C)$ and $P(E^{\#}|K) \approx 1$. But suppose we had such an argument. We could then sidestep considerations about surprisingness altogether. For it follows already from $P(E|K) \approx 1$, $P(E) \approx 0$, and P(K) being "not too small", that $P(K|E) \approx 1$, i.e. that fine-tuning is strong evidence for the multiverse hypothesis. (To see this, simply plug the values into Bayes's formula, $P(K|E) = P(E|K)P(K) / P(E)$.)

To make progress beyond this point, it is imperative to abandon vague talk of what makes events surprising and focus explicitly on the core issue, which is to determine the conditional probability of the multiverse hypothesis/chance hypothesis/design hypothesis given the evidence we have. If we figure out how to think about these conditional probabilities then we can hopefully use this insight to sort out the quandary about whether fine-tuning should be regarded as surprising. At any rate, that quandary becomes much less important if we have a direct route to assigning probabilities to the relevant hypotheses that skips the detour through the dark netherworld of amazement and surprise. This is what we shall now do.

Observational selection effects

I suggest that the only way to get a plausible model of how to reason from fine-tuning is by explicitly taking observational selection effects into account.

Selection effects, in general, are biases that make our observations unrepresentative of the domain that we are purporting to observe. For example, suppose you are trying to estimate the average length in the fish population of a lake. You catch fifty fish, and they are all longer than 20 cm. Can you reasonably infer that most fish in the lake are at least 20 cm long? – Not if you were catching the fish with a net that can catch only fish that are 20 cm or longer. Your sampling device, the net, introduces a selection effect that you need to take into account when interpreting the data. Similarly if you are conducting a poll to forecast the outcome of an election you need to consider possible selection effects, such that a higher propensity of certain groups of voters to take part in the poll. Selection effects are ubiquitous in applied statistics. They don't necessarily make our data useless, but we should seek to minimize them by sampling from as representative subpopulations as we can reach; and in cases where it is not feasible to eliminate biases in data collection, we should at least correct for known selection effects when making inferences from the resultant data.

Observations are restricted not only by limitations in our measurement devices and polling techniques but also by the requirement that there be some suitably positioned observer to conduct the polls and read off the devices (and to build the devices in the first place). The only parts of cosmos that are observed are those that have a certain physical proximity to some observer. It is therefore an error to assume that the parts of cosmos that we observe are necessarily likely to be representative of the whole. On the contrary, if cosmos is very big, and only a small part of it is visible from locations where there are observers, and we know that observers can only exist on certain atypical locations, then we know that what is observed has been subjected to a selection effect – an *observational* selection effect. Observational selection effects are no different in principle from the more humdrum selection effects that occur because of device limitations, and they are just as important to take into consideration when we are evaluating cosmological theories in light of our observations.

This section sketches the outlines a theory of observational selection effects, and it attempts to show how this theory can be used to provide a neat solution to the philosophical problems of cosmological fine-tuning.

As before, let "α" rigidly denote our universe. We know some things K about α (it's life-permitting; it contains the Eiffel tower; it's quite big etc.). Let h_M be the multiverse hypothesis; let h_D be the design hypothesis; and let h_C be the chance hypothesis. In order to determine what values to assign to the conditional probabilities $P(h_M|K)$, $P(h_D|K)$, and $P(h_C|K)$, we need to take account of the observational selection effects through which our evidence about the world was filtered.

Let's consider how one may model these observational selection effects. Suppose that you are an angel. So far nothing physical exists, but six days ago God told you that he was going away for a week to create a cosmos. He might create either a single universe or a multiverse, and let's say your prior probabilities for these two hypotheses are about 50%. Now a messenger arrives and informs you that God's work is completed. The messenger tells you that universe α exists but does not say whether there are other universes in addition. Should you think that God created a multiverse or only α? To answer this, we need to know something more about the situation. Consider two possible specifications of what happened:

> *Case 1*. The messenger decided to travel to realm of physical existence and look at the universe or one of the universes that God had created. This universe was α, and this is what he reports to you.

> *Case 2*. The messenger decided to find out whether God created α. So he travels to the realm of physical existence and looks until he finds α, and reports this back to you.

In Case 1, the messenger's tidings do not in general give you any reason to believe h_M. He was bound to bring back news about some universe, and the fact that he tells you about α rather than some other universe is not significant, *unless* α has some special feature F. (More on this proviso shortly.)

In Case 2 on the other hand, the fact that the messenger tells you that α exists is evidence for h_M. If the messenger selected α randomly from the class of all possible universes, or from some sizeable subclass thereof (for example only big bang universes with the same laws of nature as in our universe, or only universes which contain more good than evil), then the finding that God created α suggests that God created many universes.

Our actual epistemic situation is not analogous to the angel's in Case 2. It is not as if we first randomly selected α from a class containing both actual and non-actual possible universes and then discovered that – lo and behold! – α actually exists. The fact that we know whether α exists surely has everything to do with it actually existing and we being among its inhabitants. There is an observational selection effect amounting to the following: direct observation occurs only of universes that actually exist. Case 1 comes closer to modeling our epistemic situation in this respect, since it mirrors this selection effect.

However, Case 1 is still an inadequate model because it overlooks another observational effect. The messenger could have retrieved information about any of the actual universes, and the angel could have found out about some universe β that doesn't contain any observers. If there are no angels, gods or heavenly messengers, however, then universes that don't contain observers are not observed. Assuming the absence of extramundane observers, the selection effect restricts what is observed not only to the extent that non-actual universes are not observed but actual universes that don't contain any observers are also not observed. This needs to be reflected in our model. If we want to continue to use the creation story, we therefore need to modify it as follows:

> *Case 3*. The messenger decided to travel to the realm of physical existence and look for some universe that contains observers. He found α, and reports this back to you.

Does this provide you with any evidence for h_M? It depends. If you knew (call this *Case 3a*) that God had set out to create at least one observer-containing universe, then the tiding that α is actual does not give any support to h_M (unless you know that α has some special feature). Because then you were guaranteed to learn about the existence of some observer-containing universe or other and learning that it is α does not give any more evidence for h_M than if you had learnt about some other universe instead. The messenger's tidings T contain no relevant new information; the probably you assign to h_M remains unchanged. In Case 3a, therefore, $P(h_M|T) = P(h_M)$.

But there is second way of specifying Case 3. Suppose (*Case 3b*) that God did not set out especially to create at least one observer-containing universe, and that for any universe that He created there was a only a fairly small chance that it would be observer-containing. In this case, when the messenger reports that God created the observer-containing universe α, you get evidence that favors h_M. For it is more probable on h_M than it is on $\neg h_M$ that one or more observer-containing universes should exist (one of which the messenger was then bound to bring you news about). Here, we therefore have $P(h_M|T) > P(h_M)$.

What is grounding T's support for h_M? I think it is best answered by saying not that T makes it more probable that α should exist, but rather that T makes it more probable that at least one observer-containing universe should exist. It is nonetheless true that h_M makes it more probable that α should exist. But this is not by itself the reason why h_M is to be preferred given our knowledge of the existence of α. If it were, then since the same reason operates in Case 3a, we would have to have concluded that h_M were favored in that case as well. For even though it was guaranteed in Case 3a that some observer-containing universe would exist, it was not guaranteed that it would be α. In Case 3a as well as in Case 3b, the existence of α was made more likely by h_M than by $\neg h_M$. If this should not lead us to favor h_M in Case 3a then the fact that the existence of α is made more likely by h_M cannot be the whole story about why h_M is to be preferred in Case 3b.

So what is the whole story about this? In a nutshell: although h_M makes it more probable that α should exist, h_M also makes it more probable that there are other observer-containing universes. And the greater the number of observer-containing universes, the smaller the probability that we should observe any particular one of them. These two effects balance each other. The result is that the messenger's tidings are evidence in favor of theories on which it is probable that at least one observer-containing universe would exist; but this evidence does not favor theories on which it is probable that there are *many* observer-containing universes over theories on which it is probable that there are merely a *few* observer-containing universes.

We can get an intuitive grasp of this if we consider a two-step procedure. Suppose the messenger first tells you that some observer-containing universe x exists. This rules out all hypotheses on which there would be no such universes; it counts against hypotheses on which it would be very unlikely that there are any observer-containing universes; and it favors hypotheses on which it would be very likely or certain that there is one or more observer-containing universes. In the second step, the messenger tells you that $x = \alpha$. This should not change your beliefs as to how many observer-containing universes there are (assuming you don't think there is anything special about α). One might say that if God were equally likely to create any universe, then the probability that α should exist is proportional to the number of universes God created. True. But the full evidence you have is not only that α exists but also that the messenger told you about α. If the messenger selected the universe he reports randomly from the class of all actual observer-containing universes, then the probability that he would select α, given that α is an actual observer-containing universe, is *inversely* proportional to the number of actual observer-containing universes. The messenger's report therefore does not allow you to discriminate between general hypotheses[7] that imply that at least one observer-containing universe exists.

[7] By "general hypotheses" we here mean: hypotheses which don't entail anything preferentially about α. For example, a hypothesis which says "There is exactly one life-containing universe and it's not α." will obviously be refuted by the messenger's report. But the point is that there is nothing about the messenger's

In our actual situation our knowledge is not mediated by a messenger; but the suggestion is that the data we get about the world are subjected to observational selection effects that mimic the reporting biases present in Case 3.

When stating that the finding that α exists does not give us reason to think that there are many rather than few observer-containing universes, we have kept inserting the proviso that α not be "special". This is an essential qualification, for there clearly are some features F such that if we knew that α has them then finding that α exists *would* give support to claim that there are a vast number of observer-containing universes. For instance, if you know that α is a universe in which a message is inscribed in every rock, in the distribution of fixed stars seen from any life-bearing planet, and in the microstructure of common crystal lattices, spelling: "God created this universe. He also created many other universes." – then the fact that the messenger tells you that α exists can obviously give you some reason to think that there are many universes. In our actual universe, if we were to find inscriptions that we were convinced could only have been created by a divine being then this would count as support for whatever these inscriptions asserted (the degree of support being qualified by the strength of our conviction that the deity was being honest). Leaving aside such theological scenarios, there are much more humdrum features our universe might have that could make it special in the sense intended here. It may be, for example, that the physics of our universe is such as to suggest a physical theory (because it's the simplest, most elegant theory that fits the facts) which entails the existence of vast numbers of observer-containing universes.

Fine-tuning may well be a "special" feature. This is so because fine-tuning seems to indicate that there is no simple, elegant theory which entails (or gives a high

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report that gives reason to favor hypotheses only because they imply a greater number of observer-containing universes, assuming there is nothing special about α.

probability to) the existence our universe alone but not to the existence of other universes. If it were to turn out, present appearances notwithstanding, that there is such a theory then our universe is not special. But in that case there would be no reason to think that our universe really is fine-tuned. For if a simple theory entails that precisely this universe should exist, then one could plausibly assert that no other boundary conditions than those implied by that theory are physically possible; and hence that physical constants and initial conditions could not have been different than they are – thus no fine-tuning. However, assuming that every theory fitting the facts and entailing that there is only one universe is a very ad hoc one and involving many free parameters – as fine-tuning advocates argue – then the fine-tuning of our universe is a special feature that gives support to the hypothesis that there are many universes. There is nothing mysterious about this. Preferring simple theories that fit the facts to complicated ad hoc ones is just standard scientific practice, and cosmologists who work with multiverse theories are presumably pursuing that inquiry because they think that multiverse theories represent a promising route forward to neat theories that are empirically adequate.

We can now answer the questions asked at the beginning of this paper: Does fine-tuning cry out for explanation? Does it give support to the multiverse hypothesis? Beginning with the latter question, we should say: Yes, to the extent that multiverse theories are simpler, more elegant (and therefore claming a higher prior probability) than any rival theories that are compatible with what we observe. In order to be more precise about the magnitude of support, we need to determine the conditional probability that a multiverse theory gives to the observations we make. We have said something about how such conditional probabilities are determined: the conditional probability is greater – ceteris paribus – the greater the probability that the multiverse theory gives to the existence of a universe exactly like ours; it is smaller – ceteris paribus – the greater the number of observer-containing universes it entails. These two factors balance each other to the effect that if we are comparing various multiverse theories then what matters, generally speaking, is the likelihood they assign to at least some observer-containing universe existing; if two multiverse theories both do that, then there is no general reason to favor or disfavor the one that entails the larger number of observer-containing universes.

The answer to the question whether fine-tuning cries out for explanation follows from this. If something's "crying out for explanation" means that it would be unsatisfactory to leave it unexplained or to dismiss it as a chance event, then fine-tuning cries out for explanation at least to the extent that we have reason to believe in some theory that would explain it. At present, multiverse theories may look like reasonably promising candidates. For the theologically inclined, the Creator-hypothesis is also a candidate. And there remains the possibility that fine-tuning could turn out to be an illusion – if some neat single-universe theory that fits the data were to be discovered in the future.[8]

Finally, we may also ask whether there is anything surprising about our observation of fine-tuning. Let's assume, as the question presupposes, that the universe really is fine-tuned, in the sense that there is no neat single-universe theory that fits the data (but not in a sense that excludes our universe being one in an ensemble that is itself not fine-tuned). Is such fine-tuning surprising on the chance-hypothesis? It is, per assumption, a low-probability event if the chance-hypothesis is true; and it would tend to disconfirm the chance-hypothesis if there is some other hypothesis with reasonably high prior probability that assigns a high conditional probability to fine-tuning. For it to be a surprising event then (invoking Horwich's analysis) there has to be some alternative to the chance-hypothesis that meets conditions (iii) and (iv). Some would hold that the design hypothesis satisfies these criteria. But if we rule out the design hypothesis, does the multiverse hypothesis fit the bill? We can suppose, for the sake of the argument at least, that the prior probability of the multiverse hypothesis is not too low, so that (iv) is

[8] If there is a sense of "explanation" in which a multiverse theory would not explain why we observe a fine-tuned universe, then the prospect of a multiverse theory would not add to the need for explanation in that sense.

satisfied. The sticky point is condition (iii), which requires that $P(E'|h_M) \approx 1$. According to the discussion above, the conditional probability of us observing a fine-tuned universe is greater given a suitable multiverse than given the existence of a single random universe. If the multiverse hypothesis is of a suitable kind – such that it entails (or makes it highly likely) that at least one observer-containing universe exists – then the conditional probability, given that hypothesis, of us observing an observer-containing universe should be set equal (or very close) to one. It then comes down to whether on this hypothesis representative[9] observer-containing universes would be fine-tuned.[10] If they would, then it follows that this multiverse hypothesis should be taken to give a very high likelihood to our observing a fine-tuned universe; so Horwich's condition (iii) would be satisfied, and our observing fine-tuning would count as a surprising event. If, on the other hand, representative observer-containing universes in the multiverse would not be fine-tuned, then condition (iii) would not be satisfied, and the fine-tuning would not qualify as surprising.[11]

[9] The meaning of "representative" is *not* equivalent here to "most numerous type of universe in the multiverse" but rather "the type of universe with the greatest expected fraction of all observers".

[10] One can easily imagine multiverse theories on which this would not necessarily be the case. A multiverse theory could for example include a physics that allowed for two distinct regions in the space of possible boundary conditions to be life-containing. One of these regions could be very broad so that most universes in that region would not be fine-tuned – they would still have contained life even if the values of their physical constants had been slightly different. The other region could be very narrow. Universes in this region would be fine-tuned: a slight perturbation of the boundary conditions would knock a universe out of the life-containing region. If the universes in the two life-containing regions in parameter space are equivalent in other respects, this cosmos would be an instance of a multiverse where representative observer-containing universes would not be fine-tuned. If a multiverse theory assigns a high probability to the multiverse being of this kind, then on the hypothesis that that theory is true, representative observer-containing universes would not be fine-tuned.

[11] It may intuitively seem as if our observing a fine-tuned universe would be even *more* surprising if the only multiverse theory on the table implied that representative observer-containing universes were *not* fine-tuned, because it would then be even more improbable that we should live in a fine-tune universe. This intuition most likely derives from our not accepting the assumptions we made. For instance, the design hypothesis (which we ruled out by fiat) might be able to fit the four criteria and thus account for why we would find the fine-tuning surprising even in this case. Alternatively, we might think it implausible that we

Note that in answering the question whether fine-tuning was surprising, we focused on E' (the statement that there is a fine-tuned universe) rather than E (the statement that α is fine-tuned). I suggest that what is primarily surprising is E', and E is surprising only in the indirect sense of implying E'. If E is independently surprising, then on Horwich's analysis, it has to be so owing to some other alternative[12] to the chance-hypothesis than the multiverse hypothesis, since it is not the case that $P(E \mid h_M) \approx 1$. But I find it quite intuitive that what would be surprising on the chance-hypothesis is not that *this* universe (understood rigidly) should be fine-tuned but rather that there should be a fine-tuned universe at all if there is only one universe in total and fine-tuning was highly improbable.

Conclusions

It may be useful to summarize our main findings. We set out to investigate whether fine-tuning needs explaining and whether it gives support to the multiverse hypothesis. We found that:

- There is an easy part of the answer: Leaving fine-tuning unexplained is epistemically unsatisfactory to the extent that it involves accepting complicated, inelegant theories with many free parameters. If a neater theory can account for available data it is to be preferred. This is just an instance of the general methodological principle that one should prefer simpler theories, and it has nothing to do with fine-tuning as such (i.e. this point is unrelated to the fact that

would be sufficiently convinced that the only available multiverse hypotheses would be ones in which representative universes would not be fine-tuned. So this represents a rather artificial case where our intuitions could easily go astray. I discuss it only in order to round out the argument and to more fully illustrate how the reasoning works. The point is not important in itself.

[12] It's not clear whether there is an alternative that would work here. There would be if, for instance, one assigned a high prior probability to a design hypothesis on which the designer was highly likely to create only and to make it fine-tuned.

observers would not have existed if boundary conditions had been slightly different).

- Ian Hacking's argument that multiverse theories such as Wheeler's oscillating universe model cannot receive any support from fine-tuning data, while multiverse theories such as the one Hacking ascribes to Brandon Carter can receive such support, is flawed. So are the more recent arguments by Roger White and Phil Dowe purporting to show that multiverse theories *tout court* would not be supported by fine-tuning.

- Those who think fine-tuning gives some support to the multiverse hypothesis have typically tried to argue for this by appealing to the surprisingness of fine-tuning. We examined van Inwagen's straw lottery example, refuted some objections by Carlson and Olsson, and suggested a variant of Inwagen's example that is more closely analogous to our epistemic situation regarding fine-tuning. In this variant the verdict seems to favor the multiverse advocates, although there appears to be room for opposing intuitions. In order to give the idea that an appeal to the surprisingness of fine-tuning could settle the issue a full run for its money, we considered Paul Horwich's analysis of what makes the truth of a statement surprising. This analysis may provide the best available explication of what multiverse advocates mean when they talk about surprise. It was found, however, that applying Horwich's analysis to the fine-tuning situation did not suffice to settle the issue of whether fine-tuning is surprising. We concluded that in order to determine whether fine-tuning cries out for explanation or gives support for the multiverse hypothesis, it is not enough to appeal to the surprisingness or amazingness of fine-tuning. One has to drill deeper.

- What is needed is a way of determining the conditional probability $P(E|h_M)$. I suggested that in order to get this right, it is essential to take into account observational selection effects. We created an informal model of how to think about such effects in the context of fine-tuning. Some of the consequences of this model are as follows:

- Suppose there exists a universe-generating mechanism such that each universe it produces has an equal probability of being observer-containing. Then fine-tuning favors (other things equal) theories on which the mechanism has operated enough times to make it probable that at least one observer-containing universe would result.

- However, if two competing general theories with equal prior probability each implies that the mechanism operated sufficiently many times to (nearly) guarantee that at least one observer-containing universe would be produced, then our observing an observer-containing universe is (nearly) no ground for favoring the theory which entails the greater number of observer-containing universes. Nor does it matter how many observerless universes the theories say exists.

- If two competing general theories with equal prior probability, T_1 and T_2, each entails the same number of observer-containing universes (and we assume that each observer-containing universe contains the same number of observers), but T_1 makes it more likely than does T_2 that a large fraction of all the observers live in universes that have those properties that we have observed that our universe has (e.g. the same values of physical constants), then our observations favor T_1 over T_2.

- Although $P(E|h_M)$ may be much closer to zero than to one, this conditional probability could nonetheless easily be large enough (taking observational selection effects into account) for E to favor the multiverse hypothesis.

- Here is the answer to the "tricky part" of the question about whether fine-tuning needs explanation or supports the multiverse hypothesis: Yes, there is something about fine-tuning as such that adds to the need for explanation and to the support for the multiverse hypothesis over and above the general principle that simplicity is epistemically attractive. The reason for this is twofold. First, the availability of a potential rival explanation for why the universe should be observer-containing. The design hypothesis, presumably, can more plausibly be invoked to explain a world that contains observers than one that doesn't. Second (theology apart), the capacity of the multiverse hypothesis to give a high conditional probability to E (and thereby in some sense to explain E), and to gain support from E, depends essentially on observational selection effects. Fine-tuning is therefore *not* just like any other way in which a theory may require a delicate setting of various free parameters to fit the data. The presumption that observers would not be so likely to exist if the universe were not fine-tuned is essential. For that presumption entails that if a multiverse theory implies that there is an ensemble of universes, only a few of which are fine-tuned, then what the theory predicts that we should observe is still one of those exceptional universes that are fine-tuned. The observational selection effect enables the theory to give our observing a fine-tuned universe a high conditional probability even though such a universe may be very atypical of cosmos as a whole. If there were no observational selection effect restricting our observation to an atypical proper part of cosmos, then postulating a bigger cosmos would not in general give a higher greater conditional probability of us observing some particular feature. (It may make it more probable that that feature should be instantiated somewhere or other, but it would also make it less probable that we should happen to be at any particular place where it was instantiated.) Fine-tuning, therefore, involves issues additional to the ones common to all forms of scientific inference and explanation.

- On Horwich's analysis of what makes the truth of a statement surprising, it would be surprising against the background of the chance-hypothesis that only one universe existed and it happened to be fine-tuned. By contrast, that *this* universe should be fine-tuned would not contain any additional surprise factor (unless the design hypothesis could furnish an explanation for this datum satisfying Horwich's condition (iii) and (iv)).

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