# FINE-TUNING THE MULTIVERSE

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Gottfried Wilhelm Leibniz (1646–1716) was quite a thinker. As a philosopher, he made major contributions to epistemology, logic, the philosophy of religion and metaphysics. He was also an accomplished scientist, historian, and linguist. In mathematics, he built the first (admittedly somewhat unreliable) calculating machine able to perform all four elementary arithmetical operations, and devised the first proper formulation of binary numbers. Although Chinese and Indian scholars had developed several types of rudimentary binary notation centuries earlier, the number system at the heart of every modern computer was put together by Leibniz. As if that were not enough to guarantee his immortality, he also developed calculus independently of Isaac Newton, and it is mostly Leibniz's version that survives in our textbooks, due to his superior notation.

## Possible worlds

Leibniz wondered about the possibility of other worlds different from our own. Medieval philosopher-theologians had already rejected Aristotle's view that other worlds were impossible, since they thought such a view to be at odds with God's omnipotence, and for centuries philosophers had been toying with the notion that God would have created the best of all possible worlds. (Confusingly, philosophers and physicists use 'possible worlds' and 'possible universes' interchangeably.) Leibniz, a key figure in the scientific revolution, cast the problem in terms of the laws of nature. Even God, reasoned Leibniz, couldn't make just *any* universe. The principle of non-contradiction required

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that He couldn't build a universe in which physical laws conflicted with each other, any more than He could create a square circle.

Furthermore, Leibniz could see no limit on the number of combinations of consistent physical laws. God could have created the universe according to any of these permutations, but being omnibenevolent, omniscient and omnipotent, He would have chosen the best. Thus Leibniz concluded that the world, despite apparent faults, must in some sense be the best one possible.

Leibniz may have clarified the idea of other possible universes, but he didn't think more than one of them actually exists. Could there be more than one real universe? If so, the collection of all universes is usually referred to as the 'multiverse', the term having been minted in a completely different context by the American philosopher William James in his 1895 essay *Is Life Worth Living?* Any reader of popular science books and periodicals will almost certainly have encountered the multiverse, chiefly because in the minds of many theoretical physicists, it solves what is known as the 'fine-tuning problem'.

## Fine-tuning

Our existence is extremely precarious. For example, if protons were just slightly heavier, they would decay into other particles. Without protons there would be no atoms with which to make living things. A similar story is repeated with practically every basic property of the universe we come across. Change any one of these parameters, and the universe would be a lifeless and probably even featureless place. In *Just Six Numbers,* Professor Sir Martin Rees describes half a dozen such cosmic flukes, then points out that '. . .if any one of them were to be "untuned", there would be no stars and no life'.

There is not a total consensus; if all the parameters are allowed to vary at once, complex structures of some kind

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might still arise. But for now, pending improvement of the theories needed to bolster such possibilities, most physicists agree that fine-tuning seems far too convenient to be merely overlooked. So what are we to make of these apparent coincidences?

## Design

One possibility is that the universe appears to be fine-tuned for life because it actually *was* fine-tuned for life. It is certainly true that if the universe was created by God, then fine-tuning would be no surprise. The validity of the reverse implication, that the appearance of design implies actual design, is somewhat doubtful. Such 'teleological' arguments have a history of collapsing in the face of advancing knowledge. Over the millennia, gods have been held responsible for the form of plants and animals, plague, the motion of the sun, and even the weather, but when non-supernatural explanations for such phenomena were subsequently identified, the currency of the whole line of reasoning was severely devalued.

Furthermore, on their own, teleological arguments tell us next to nothing about the designer. God is only one possibility: why not several gods? Or an evil god? There is even an intriguing recent argument put forward by Nick Bostrom and others, that our universe might be a simulation.

But it is not our purpose to survey centuries of debate over teleological arguments, fascinating as that would be. What concerns us is whether the multiverse is a good explanation of fine-tuning, and whether it exists.

## Anthropic reasoning

Have you ever considered the incredible number of unlikely coincidences that make life on Earth possible? It has a magnetic field just strong enough to fend off deadly



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radiation from the Sun; it is exactly the right distance from our parent star to allow the existence of liquid water . . . and the list goes on. So how did the big blue marble come to be so exquisitely fine-tuned for life? Well, there are so many planets in the universe that even if the overwhelming majority are uninhabitable there will still be plenty that could support life. Since only habitable planets can evolve and sustain sentient beings capable of asking such questions, it is no surprise whatsoever that we happen to find ourselves on one of them. The apparent coincidence is completely dissolved.

As a way of explaining life-supporting conditions on Earth the above argument is perfectly reasonable, but can it be scaled up? Stronger 'anthropic' reasoning comes in various forms, many of them unobjectionable enough. For example, from the fact that we exist, the density of the 'dark energy' which drives the expansion of the universe (sometimes called the 'cosmological constant') can be derived with almost uncanny precision. Using anthropic reasoning to make such predictions is perfectly acceptable, but to turn it into an explanation of *why* the cosmological constant has its observed value, we need to throw in some questionable statistical selection effects as well.

Suppose there exists a huge number of disconnected universes, each featuring different conditions (cosmological constant, mass of the proton and so on), or even with entirely different laws of physics. Even if most are featureless and uninhabitable, if there are sufficiently many variations, the conditions will be right for life in a few of these universes. Problem solved? Rees has written: 'If our universe is selected from a multiverse, its seemingly designed or fine-tuned features would not be surprising,' which seems sound enough. But like the design argument, logical difficulties surface if we try to turn the implication around. Just because a multiverse would make fine tuning unsurprising, does the fact of fine-tuning mean the multiverse is really there?

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Such reasoning does provide *some* support for the multiverse – after all we might have guessed the existence of other planets based on the properties of the Earth. Unfortunately, to infer the existence of other universes from apparently coincidental conditions in this one is a very weak argument on its own, as should be clear from an example. Suppose you started tossing a coin and got an immediate run of 100 heads. You would rightly think this was rather curious, but in the absence of other data or better arguments, the most reasonable explanation would be that the coin was not fair.

## A deeper theory

What goes for coins also goes for universes. There might be as yet undiscovered principles in play that shepherd the universe towards the outcome we observe. Physical constants such as the mass of the proton might arise naturally in some as yet undiscovered theory of physics. If we could uncover such laws, we might even find that a universe like this one was almost inevitable. Perhaps if we knew more about the coin, we would discover that it has heads on both sides.

Hints of this deeper theory do exist. A theoretical device known as the 'holographic principle' can (tentatively) be used to derive the cosmological constant; but such arguments are still somewhat speculative at this stage.

We have no idea how long a proper explanation of fine-tuning in terms of a deeper theory might take to find, but nor do we have any particular reason – other than a history of failure – to suppose that no such theory is possible. It is certainly far too early to give up, but if there is a deeper (single universe) theory to be had, we are nowhere near finding it despite intense effort. For this reason alone, we might be tempted to sympathise with the growing number of physicists who regard the multiverse as being a better explanation of fine-tuning. To make the multiverse



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plausible however, we need something much more convincing than the back-to-front statistical reasoning described earlier.

## Multiverses everywhere

A better argument for the multiverse is that in practice it is proving almost impossible to manufacture any theory that matches observation and yet doesn't predict one. Theories including eternal inflation, string theory and the 'many worlds' interpretation of quantum mechanics – to name just a few – all suggest the existence of a multiverse. According to which theory you prefer, the extra universes might be separated by tremendous distances, be embedded in different spatial dimensions, or might be separated only by time. Fortunately we needn't worry too much about the details because as regards the fine-tuning problem, all multiverses are more or less equivalent – with one exception, as we shall see later.

The fact that all the theories on the table have similar ramifications, coupled with our striking lack of success in finding a deeper theory for a single universe, lends support to the multiverse because it acts in opposition to a difficulty known as 'underdetermination by the evidence', which says that no matter how much evidence we accumulate, more than one theory can always be made to fit. Some philosophers of science go as far as to say that as a result of underdetermination, no one theory should ever be considered 'true', and unobservable entities, such as other universes or (incorrectly in my view) quarks, should never be considered 'real'.

At the coal face of science, however, it is usually extraordinarily difficult to find even *one* theory that fits the facts. In the current context, we do have a few competing theories, but they all imply broadly the same thing: a multiverse. Although these remarks don't neutralise the underdetermination problem completely, they do give those

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who are overly impressed by it some explaining to do. Why in practice do so few theories seem to fit the evidence? And if the majority of theories we can find that do fit the facts have similar implications, surely that in itself is significant?

## Induction

Another reason for taking the multiverse seriously is the many impressive predictions previously made by scientific theories. For example positrons, which are similar to electrons except with the opposite electrical charge, were discovered in the mathematics of Paul Dirac before any were actually detected, but these days the real thing can routinely be found in medical scanners. In general, the more tests a theory passes, particularly if the results would be surprising in the absence of the theory, the more confidence scientists feel justified in having about the theory and its other predictions. When predictions fail, scientists modify or replace the theory.

Despite this being a reasonable description of the way science works in practice, philosophers have strong reservations. Ever since David Hume first identified his famous problem with evidence-based 'inductive reasoning' (to summarise: turkeys have good evidence that farmers are friendly – until the day they discover the hard way that this theory is completely false), philosophers have wrestled with the problem. In the twentieth century, Sir Karl Popper tried to circumvent the problem of induction by saying there is little point in seeking evidence that confirms a theory. Scientists should try to *dis*prove ('falsify') theories, by finding contrary evidence. These days, most philosophers think that Popper went too far in his misgivings about positive evidence, and that it does contribute something – though exactly what is still hotly debated.

Unfortunately, direct evidence for the multiverse is effectively out of the question anyway, because anything we can



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actually measure or observe is necessarily part of this universe, not another one. Indirect evidence might be possible though. For example, one of the first people to argue for a multiverse was Andrei Linde, the distinguished Russian physicist now at Stanford. Linde's multiverse is an adaptation of the 'inflation' that is widely held to have rapidly boosted the size of the universe shortly after the big bang, in which inflation continually spawns new disconnected regions of space, each with different properties. Researchers have recently noticed that the cosmic microwave background radiation – the echo left over from the big bang – contains traces of what might be 'bruises' caused by collisions between Linde's other universes and our own. These observations are certainly interesting, but such extremely indirect evidence is very difficult to decipher without making lots of theoretical assumptions – the underdetermination problem again – and only becomes convincing when we have good reason for ruling out alternative interpretations.

The fact that the multiverse is predicted by several theories that have a good track record of successful forecasts is far from conclusive, but it is significantly better than the back-to-front statistical reasoning outlined earlier.

## Falsification

What evidence would *rule out* the multiverse? Although the philosophy of science has moved on since Popper, philosophers still regard susceptibility to falsification as being a key feature of good scientific theories, and statements that are *not* falsifiable as being highly dubious. It is so easy to invent crackpot notions immune from falsification ('Invisible aliens replaced my car with an exact copy!'), that even reasonable-sounding unfalsifiable statements are tainted by association. Whether the multiverse is falsifiable is the subject of lively and sometimes acrimonious debate. An infamous online spat between the well-known physicists Lee Smolin and Leonard Susskind, who took opposing

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views on the matter, was only brought to a halt when both men agreed to make one final post and call a truce.

In a way, Smolin and Susskind were both correct. Any respectable multiverse theory – some variant of string theory say – will be able to make predictions about *our* universe and these can be tested. If the theory fails a test, it is duly falsified; hence multiverse theories are falsifiable. But demonstrating a particular theory to be incorrect doesn't show the multiverse is not there. Broad, non-theory-specific claims about the existence of other universes are too flexible to be susceptible to falsification. Any observation we can make will always be compatible with a multiverse of some sort, so there is no way to rule out every possible multiverse.

What if a multiverse theory passes an attempted falsification test? With the problem of induction in mind, we must be careful not to over-interpret such a result. Confirmation of a test such as the existence of a previously unexpected force or surprising new particle not predicted by other theories would be good support for the theory in question. As such evidence accumulates it would be fair to gradually give more credence to a multiverse predicted by the same theory.

Conversely, empirical confirmation of, say, the value of the cosmological constant predicted by means of a statistical anthropic selection effect across the multiverse, is exceedingly poor support for any theory. The use of anthropic reasoning to anticipate the value of such things is perfectly acceptable, but it doesn't provide support for the multiverse, because unlike the search for a new particle, it cannot fail. There is no possibility that we will measure the cosmological constant and discover that it has a value incompatible with our own existence, and we know this prior to any particular theory. Apart from uninteresting theories that don't allow our existence at all, such a 'test' lends equal support to *all* theories – and hence no support to any of them. The main fault with much that is written about the multiverse in popular literature lies in appearing to attribute significance to anthropic selection effects that seem superficially impressive, but actually provide no support for the multiverse whatsoever. At



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best this is shoddy reasoning. At worst, it risks bringing the whole of physics into disrepute, since it hands ammunition to those who like to accuse scientists of allowing unsupported fantasy into supposedly factual scientific theories, providing only that it is not overtly supernatural in character.



## Back to fine-tuning

The number of universes being suggested by physicists is truly staggering. For example, the number of universes consistent with M-theory (a promising branch of string theory) is $10^{500}$ (1 followed by 500 zeroes) – a number so colossal that the number of atoms in our universe is insignificant by comparison. Other predictions make even this figure look small.

Suppose then that a unified theory of physics, ‘M’, is eventually devised that is quantifiable, simple, consistent, falsifiable and that predicts a multiverse of $10^{500}$ universes (or any other number). Suppose M’s other predictions survive every experimental test – many of them unexpected and surprising – for a hundred years. Although it would still be going too far to say M shows the multiverse is definitely real, in the face of M’s success you’d have to be fairly brave to still think the multiverse was complete baloney. This would be especially true if all the other theories discarded along the way had also predicted a multiverse. There is still, however, the possibility of M being trumped by a single-universe theory ‘S’ that doesn’t rely on arbitrary parameters. Given the current state of physics it looks far more likely that we’ll find M than that we’ll ever find S, but even if S could be found, it would still have a weakness – which turns out also to afflict M.

## Maths and physics

At the heart of fundamental theories of physics lie mathematical structures which are put into a correspondence (‘homomorphism’) with observation, in such a way that the

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mathematics mirrors the relevantly similar properties of the physical world. Despite its stunning success, this approach does raise questions about what type of explanation physics provides. It certainly facilitates startlingly accurate predictions. Otherwise intractably complex and baffling aspects of reality are often reduced to simple and unavoidable mathematical consequences of the theory. But the result is somewhat like a model, and while a sufficiently good model of an aeroplane might tell you everything you are ever likely to need to know about the real thing, it doesn't tell you why you happen to be travelling in an aeroplane rather than something else.

Further, even if we can find some mathematics that delivers S, we will have infinitely many equally splendid mathematical contraptions left over, unused. Leibniz solved this problem by invoking God to explain why only one possible world – the best – was realised. To get a similar result without resort to either the supernatural or to brute unexplained observation, would require additional reasoning to rule out the infinitely many structures that nature has chosen to ignore. Unfortunately, such logic is almost certainly not available – for example as far as we can tell, there is no logical prohibition on a universe completely devoid of matter and forces. Given S, the puzzle of why nature has chosen to conform to S rather than some other structure would be a fine-tuning problem of a different kind.

Now, just as there is no limit on the number of Leibniz's possible universes, so there is no limit on the number of *possible multiverses*. Some possible multiverses will harbour a universe like ours, but many – perhaps the majority – will not. Whether there are $10^{500}$ universes or just one makes no difference; we need to know why nature has shunned infinitely many possible, but non-existent, worlds.

## Perhaps anything that can happen, happens

Maybe nature hasn't shunned them. In *On the Plurality of Worlds* the celebrated philosopher David Lewis (1941–



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2001) set out his proposition of *modal realism* – the notion that all possible worlds are actually existing universes. Lewis's reasoning was somewhat different from that currently being advanced by physicists, but the problem-solving power of the infinite multiverse hasn't been lost on physicists either. Max Tegmark, professor of physics at MIT, has written that perhaps '. . . all mathematical structures exist physically as well. Every mathematical structure corresponds to a parallel universe.'

Lewis and Tegmark are not merely suggesting an infinite multiverse. Such a reality could still omit infinitely many possible worlds, just as the infinite set of whole numbers is still missing infinitely many numbers such as pi and its brethren. To avoid the same kind of finely-tuned model conundrum as a finite multiverse, we need to take the brakes off and allow the existence of *every* universe that is not forbidden by some weak overarching principle such as Leibniz's consistency criterion.

This infinite multiverse finally banishes model-selection fine-tuning because it relies on no inexplicable conditions even at the multiverse level. Any sentient being thinking about the problem could only be doing so from the comfort of one of the inhabitable universes and that is all there is to be said on the matter. But are physicists seriously suggesting that we solve the problem by summoning infinitely many universes, none of which can be observed directly? Haven't they heard of Occam's razor: 'entities should not be multiplied beyond necessity'?

## Be careful with that razor

First impressions can easily lead us astray in the search for the simplest solution. The infinite multiverse is actually simpler than any particular multiverse or universe, precisely because it can be specified with fewer conditions. The situation is comparable to the set of real numbers. Individually, the vast majority of real numbers can only be specified with an infinite amount of information, by listing every digit after

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the decimal point. The whole set on the other hand can be specified with hardly any information at all. Thus, despite first appearances, the infinite multiverse does lie on the right side of Occam's razor. It's the simplest possible model – it just happens to have the most possible universes as an outcome.

But we shouldn't pretend that any of this is compelling. A specific multiverse, such as one derived from string theory, may eventually come to be regarded as being supported indirectly by certain types of evidence; but statistical anthropic selection that cannot fail isn't up to the task. Conceptually, the infinite multiverse has much to commend it, because it fixes both the parameter fine-tuning problem, and the riddle of unused mathematical structures that finite multiverses leave unresolved. It's also the simplest model; but that doesn't prove its existence. Falsifiability is a serious problem for a theory where 'anything goes', as is the impossibility of direct evidence in favour. Nor does the infinite multiverse solve the old philosophical chestnut of why there is something rather than nothing. What types of universe would meet the consistency criterion anyway? And which infinite cardinal (there are infinitely many!) should be used to measure all those universes, and why?

Finite or infinite, the multiverse is proving theoretically fruitful and is certainly worthy of further research. But concerning its actual existence, it is best at this stage to follow the wise counsel of Steven Weinberg. The Nobel Physics Laureate acknowledges that the multiverse is a useful and intriguing idea with some good theoretical support, but on reading that Andrei Linde was willing to bet his life on its existence, and that Martin Rees was willing to bet the life of his dog, Weinberg wrote, 'I have just enough confidence about the multiverse to bet the lives of both Andrei Linde *and* Martin Rees's dog.'

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