The Fine-Tuning Argument

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Introduction

As Carly Simon would say, this song ain't about you. *(Jon Stewart, the Daily Show, 13th March 2009)*

Assuming that the constants of Nature - values which determine the structure and nature of the universe - can vary, and assuming that slight variations of them would have disastrous consequences for the existence of complex life, it is tempting to conclude that the universe is fine-tuned for our existence. This is the conclusion of the fine-tuning argument, summarized as follows by the apologist William Lane Craig ("Reasonable Faith (3rd edition)"):

1. The constants of nature are fine-tuned for the emergence of complex life.
2. The fine-tuning is due to physical necessity, chance, or design.
3. It is not due to physical necessity or chance.
4. Therefore, it is due to design.

If this argument is sound, it follows that there exists a Fine Tuner of some sort. This Fine-Tuner does not, of course, have to be anything like the Trinitarian God of Christianity, but surprisingly often this unwarranted leap is made. We aim to show in this article that the argument is fundamentally unsound. There is not only no need for a designer, but the idea of our universe being designed for life, let alone humans, makes no sense, either scientifically or logically.

Several numerical constants appear in the laws of physics. To take one example, Newton's law of gravity states that the gravitational force between any two particles is proportional to the product of their masses, and inversely proportional to the square of the distance between them. The constant of proportionality is not determined by the theory, but has to be measured in experiments. Newton's law of gravity is just an approximation to Einstein's general theory of relativity, but the same constant appears in his theory and plays the same role in determining the strength of the gravitational force.

Electromagnetism, the weak nuclear force (involved in radioactive decay) and the strong nuclear force (holds the atomic nucleus and its components together) all have strengths determined by constants that have to be measured. The masses of most elementary particles are not predicted by current theories, and some of the fundamental parameters that describe our universe, like the current expansion rate, are also numbers we cannot predict, but have to measure.

If we assume that the constants describing the strength of gravity, electromagnetism, nuclear forces, and the large-scale structure of the universe could have been different, and calculate the properties of hypothetical universes where these numbers are allowed to vary from their values in ours, it has been claimed that we more often than not end up with universes where no life is possible. Stars would burn up their nuclear fuel before life could evolve on an orbiting planet, or the universe would contain so little hydrogen that stars could not form at all. Carbon and water, ingredients believed to be crucial for the origin and evolution of life, would never form.

The fine-tuning argument is a cousin of the argument from design in the biological realm. “Sophisticated” theists may no longer argue that the complexity of organic life points to a designer, but a large number of them appeal to the apparent fine-tuning of the laws of nature as an argument that a supernatural mind created the universe. Nothing in the argument warrants the leap to a “supernatural” mind. Just like the old design argument, the fine-tuning argument is an argument from analogy, so even if it is sound we are only allowed to conclude that a mind created the universe. One might suspect that the immediate introduction of a supernatural mind is made in an attempt to avoid the obvious question of who designed the Designer, or who tuned the Fine Tuner. So, even if it is sound, the fine-tuning argument proves rather less than the theist may want to establish. But the argument as it stands is not sound, and in the following we will exhibit some of the many weak points of this argument.

What exactly is to be fine-tuned

If we grant that it makes sense to talk about the constants of nature as being tunable, we should ask how many we have to play with when constructing hypothetical universes. It is important to note that discussions of fine tuning must be phrased in terms of dimensionless parameters. Otherwise a parameter can be made to look fine-tuned simply by changing the system of units. The important fact about the electron mass is not that its value is 9.11×10^{-31} kilos, but that it is approximately 1/1836 of the proton mass. In a paper published in 2006, Tegmark, Aguirre, Rees and Wilczek (http://arxiv.org/abs/astro-ph/0511774) list 31 dimensionless parameters that determine the structure of the Universe. Of these, 20 determine the properties of the Standard Model of particle physics (our current best understanding of the smallest components of the physical world), while 11 determine the large-scale properties of the Universe. This list of parameters reflects our current knowledge. A large majority of physicists think that the Standard Model is not the final word, and are looking for a more fundamental model with fewer free parameters, which would reveal deeper relationships. The Standard Model includes the discovery that two of the four forces of physics – electromagnetism and the weak force - are different aspects of a single "electroweak" interaction. Further efforts to unify things, the "Grand Unified Theories", are attempts at writing down a unified theory of the strong and electroweak interactions, and provide relations between the strengths of the two forces and relations between particle masses. Although none of the proposed GUTs have been successful so far, the consensus is that it must be possible to find a working GUT.

One of the most popular attempts to unify the forces of physics is String Theory, which describes all the particles as different vibrational patterns of a single object: the String. This is an interesting but controversial idea which has gained wide publicity in the popular science media, with its requirement that the universe in reality has 11 dimensions, one of time and 10 of space. In the early days of string theory, the theory was thought to have only one free parameter, the string tension. The mainstream opinion today, however, seems to be that there is a lot of freedom involved in the way that the theory deals with the fact that we see only 3 dimensions of space at large scales, not 10, so it is probably prudent to assume that the fundamental laws of physics will still contain a number of adjustable parameters even if string theory should turn out to be correct.

Most of the cosmological parameters are not truly fundamental either. Astronomical observations of gravitational interactions strongly suggest that the vast majority of matter in the universe is invisible (and is called "Dark Matter" because of this). Dark matter is probably some kind of heavy, weakly interacting relic particle produced in the early universe (known affectionately as a WIMP: Weakly Interacting Massive Particle), and its contribution to the density of the universe is in that case calculable from particle physics models. The initial amplitude and shape of the density fluctuations that later became stars and galaxies should also be calculable once we find a theory of particle physics beyond the Standard Model.

Another assumption in most fine-tuning calculations is that all values of the fundamental parameters are equally likely. The basis for this assumption is our ignorance of physics at high energies. We cannot exclude that the correct probability distributions for some of the free parameters may be more complex, showing that some values are more likely than others.

To summarize this section, it is likely that the true number of fundamental constants that can vary is smaller than the 31 parameters Tegmark et al. consider, and that not all values of those that can vary are equally likely. Until we have better theories of physics beyond the Standard Model and a working theory of quantum gravity, we don't really know to what extent fine-tuning is an issue.

Why think that the parameters are fine-tuned?

First, let us look at stars. Life on Earth depends on low-entropy energy supplied by the Sun. For complex organisms to arise, the energy provided by the Sun must be stable on evolutionary timescales. The Sun is a so-called main sequence star, producing its energy by fusing hydrogen to helium in its core.

The star is kept in mechanical equilibrium by the balance between the thermal pressure and gravitational forces. This balance also determines the temperature at the core of the star, and this temperature must be high enough to ignite hydrogen fusion. Matter in the star is highly ionized and the photons produced in the fusion reactions in the core cannot travel freely out to the surface. One can make simple estimates of the order of magnitude of all these effects, and their combination determines the lifetime of a main sequence star to be

$$t_s = \frac{\alpha^2}{\alpha_G}\left(\frac{m_p}{m_e}\right)^2 \frac{h}{m_p c^2}$$

Here α is the so-called fine structure constant, a dimensionless measure of the strength of electromagnetic forces, α_G is the dimensionless strength of the gravitational force, m_p and m_e are, respectively, the proton and electron mass, c is the speed of light, and h is Planck's constant. This is only a rough estimate, but gets the relationship of the main sequence lifetime of a star to the fundamental constants right in essence.

For the measured values of the physical constants t_s turns out to be a few billion years. This is probably necessary to allow enough time for complex life to evolve on an orbiting planet. However, we see that if we, for example, reduce the fine structure constant by a factor of three, the lifetime goes down by a factor of nine which makes probably gives to little time for complex life to evolve.

A universe without structures would probably not contain complex life. The standard scenario for formation of galaxies and stars in the universe is that the matter density in the universe in its earliest stages was higher in some places than in others, and that these small irregularities grew by gravitational collapse to become the structures we see around us today. The physics of this process is fairly simple: a region where the density is higher than in the regions surrounding it will attract matter, grow denser, and eventually collapse to a gravitationally bound object. Working against this collapse is the pressure in the region and the expansion of the universe, which dilute the matter. If the expansion rate of the universe is too high, collapse is prevented.

The expansion rate of the universe at any time is determined by the initial conditions of the Big Bang and by the mass-energy density. Observations indicate that the expansion rate has been increasing for the last few billions of years. The simplest explanation is that there is a small residual quantum mechanical vacuum energy. To explain the observations, the vacuum energy must contribute around 70 percent of the total energy density of the universe today.

Structure formation becomes difficult when the vacuum energy dominates the expansion. Matter is diluted faster than it can collapse, so if the chunks are not already large enough to be bound by their own gravitational field by the time vacuum energy starts to dominate, they will stop growing. If the vacuum energy had been slightly larger, we would probably not have been here.

The life-times of main-sequence stars and structure formation are just two examples of how the universe would have been inhospitable to creatures like us if the constants of nature had been different.

Not-so-fine-tuning

One of the many arguments against intelligent design in biology is the fact that there are so many examples of sub-optimal design. The same counterargument can be given to some examples of fine-tuning. Take the vacuum energy as an example: someone who wanted to design a universe where the probability of life arising somewhere is maximal should make sure to tune the vacuum energy to exactly zero, since this would make structure formation easier. The fact that we seem to live in a universe where the vacuum energy allows for structure formation, but does not have the “best” value it could have makes it look rather like our universe is a result of blind naturalistic processes.

Some of the arguments for fine tuning are decidedly strange. They self-destruct. One such argument is that the universe is so finely tuned for life that it just manages to arise. In this universe, life is so rare, and requires an environment so fragile that if physics were just a little different, it would be impossible. And yet, this fragility is supposed to reveal careful design.

Consider someone struggling across a desert, barely able to walk, but managing to keep going. She has a flask of water which contains just enough to keep her able to struggle on, through careful but painful rationing. She finally reaches a village, and the inhabitants welcome her in. A few days later, sitting in a cafe, she tells the waiter her story. The waiter is not sympathetic: "How could you complain?", he says, "the desert was clearly fine-tuned for your existence. You are here now, you had water enough to survive. You did not succumb to heat stroke".

So much for fine tuning. But is life so fragile, so improbable? Is the universe really a desert, in which life struggles to exist? In a recent New Scientist article the theist biologist Simon Conway Morris talks about life being "a spectacular tightrope walk on a gossamer thread between vast regions of crystalline immobility and chaotic flux".

Life can appear fragile to us. It seems like a fire, fueled by the directed flows of entropy that are inevitable in a universe like ours, and it re-lights again and again from the embers remaining after each mass extinction. But that is the parochial view of an ape that numbers merely in the billions. The bacteria, the archaea, the insects, the fungi hardly noticed the extinction. The taller flames were put out for a while, but the soil and even the rocks beneath have been burning with life like a furnace.

Between order and chaos there is a boundary, but it isn't a tightrope, it's a solid bridge with the strong foundations of thermodynamics. The point is that there has to be a border, somewhere, and that is going to to be interesting - how could the interaction between static order and dynamic chaos be anything but?

That interaction may not occur often in our universe, but because gravity concentrates gas into fusing spheres that shine low entropy radiation onto orbiting balls of rock, it has happened at least once, and perhaps many, many other times as well.

Each organism may be improbable, one out of countless possibilities. Each may be transient and vulnerable, yet life may be inevitable, and not just in a universe like ours. Wherever order and chaos interact, there is the possibility of replicating structures feeding off that interaction, leading to life.

Has fine-tuning been established?

Almost all discussions of fine-tuning are phrased in the form: “If we change parameter X by just a tiny amount, life becomes impossible”. But there are, allegedly, 31 parameters that can be changed, and what happens if we allow all of them to vary at the same time? It is entirely plausible that the damage done by changing one of them, can be compensated for by adjusting one or more of the others. In the example with the life-times of main-sequence stars above, we saw that reducing the strength of electromagnetism by a factor of three reduced the life time by a factor of nine. But we could have compensated for that by reducing the strength of gravity by a factor of nine. So it is clearly important to allow more than one parameter to vary in order to map out the landscape of probabilities.

Carrying out a completely satisfactory investigation along these lines is an enormous task involving calculating everything from the large-scale properties of the universe to the details of chemistry and nuclear physics.

Fred Adams (http://arxiv.org/abs/0807.3697) has investigated the problem of the life times of stars in more detail, allowing all relevant parameters to vary. His conclusion was that stable, long-lived stars existed in vast regions of parameter space.

Furthermore, Anthony Aguirre (http://arxiv.org/abs/astro-ph/0106143) has shown that a model with radically different parameters than our universe, a so-called Cold Big Bang model, should provide conditions suitable for life.

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The origin of the second law of thermodynamics

Entropy is an important concept in physics. It can, somewhat simplistically, be looked on as a measure of order. More precisely, for a system in a given state A, the entropy is the logarithm of the number of ways in which the state A can be realized.

The second law of thermodynamics says that the entropy of an isolated system always increases. Applied to the universe as a whole, this does not mean that disorder has to increase everywhere, all the time., but it does mean that increased order somewhere is always more than compensated for by increased disorder somewhere else.

The second law serves to give us an arrow of time. The microscopic laws of physics, like Maxwell’s equations and the rules of quantum mechanics, do not single out a direction for time. But the second law says that the universe as a whole evolves towards states of increasing entropy, and hence distinguishes between past and future states.

Where does the second law come from? A common "derivation" goes as follows: Consider the different microscopic states of a system as points in a huge multi-dimensional space. A given macroscopic state can usually be realized in many different ways. For example, a given total energy for a gas can be obtained by distributing it among its molecules in more than one way. Macroscopic states can therefore be pictured as volumes in the space of microscopic states. Large volumes correspond to states that can be obtained in many different ways, and therefore means large entropies.

Consider the state of the system at a given time t. We can in principle predict the future path of the system through state-space by applying the relevant microscopic equations of motion. However, without doing that we can predict that at a later time the system is likely to be in a box with larger state-space volume, simply because the probability of the system being found in a given macroscopic state is proportional to the volume of state-space the box occupies. And increasing volume means increasing entropy, so we should therefore expect the entropy to increase with time.

Roger Penrose (see "The Road to Reality", chapter 27) has criticized this argument on the grounds that it applies equally well backwards in time as it does forwards in time. The microscopic equations of motion do not distinguish between past and future, and if we asked where the system was likely to be before time t, we would by the same argument conclude that it was in a macroscopic state corresponding to a larger state-space volume.

To have a second law of thermodynamics, the initial state of the universe must have been one of very low entropy. In his book "The comprehensible cosmos" (in "Mathematical Supplement G") Victor Stenger puts forward an argument for the second law based on the notion that the largest entropy for a system of a given radius is obtained by having it form a black hole. Since the universe is clearly not a black hole, its entropy is not as high as it could be. And this would be true at any time during the expansion. So no matter how high the entropy of the universe is, it is never as high as it could be.

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But what about the initial state of the universe? This is a curious point in Stenger's argument. He claims that at the earliest time we can talk about, the Planck time where quantum gravity dominates, the universe was a black hole of the size of the Planck length. This allows him to say that the initial state of the universe was not special, since this is a maximum-entropy configuration. But it opens up the question of why the universe should start to expand from this configuration at all. If the universe was in a state of maximal entropy at the Planck time, why did anything happen at all?

There are also problems with talking about the maximum entropy *at a given time*. The concept of entropy refers to the space of all states of the system, and so it is of little use to say that the entropy could have been larger at a given time t. The real question is why the initial state of the universe was not a gigantic black hole.

The entropy of the universe today is, it can be argued, dominated by contributions from super-massive black holes like the one near the center of the Milky Way. A rough order-of-magnitude estimate of their total entropy gives (in appropriate units) 10^{100}.

The observable universe contains about 10^{80} baryons (protons, neutrons and, by cosmologist's convention, electrons). If we crushed them into a black hole, its entropy would be roughly 10^{123}. Since the number of baryons is conserved as the universe expands, this is a measure of the maximum entropy of the observable universe.

Recall that the entropy is the logarithm of the phase-space volume occupied by the state of the system. This means that the ratio of the volume occupied by the universe today to the maximum available is the staggeringly low number ten to the power of 10^{100} divided by ten to the power of 10^{123}. At earlier times, the ratio must have been even smaller.

This means, according to Penrose, the initial state of the universe must have been fine-tuned beyond comprehension. That the tiny fraction of state space represented by our universe should have been picked out by sheer luck seems just too good to be true. And yet, here we are.

Does this amount to a mathematical demonstration that the origin of the universe must have been supernatural? Not quite. Penrose's point is only that there is something extraordinary about the Big Bang that cries out for an explanation, not that the explanation is supernatural. He takes the origin of the second law of thermodynamics as a sign of the need for a better understanding of gravity and how it fits together with the principles of quantum mechanics. He suggests a physical principle, the so-called Weyl curvature conjecture, which would put an enormous restriction on the types of initial states available to the universe.

There are other proposals for how a low-entropy initial state can arise naturally. Sean Carroll and Jennifer Chen suggested in a paper in 2004 (http://arxiv.org/abs/hep-th/0410270) an explanation that involves inflation. They start by pointing out that black holes are not states of maximum entropy. They emit thermal Hawking radiation, and in the process the entropy of the universe increases. Carroll and Chen argue that, contrary to Stenger's claim, the maximum-entropy configuration in a theory with gravity is flat, empty space. They then go on to argue that thermal fluctuations caused by the cosmological constant would every now and then case a small patch of space to undergo inflation, and end up somewhat like our observable universe.

It remains to be seen which, if any, of these ideas are correct. The question of the initial state of the universe is intimately tied to the concept of entropy in situations where gravity is important. A full understanding requires knowledge of the fundamental degrees of freedom in gravity, and this in turn requires a quantum theory of gravity. However, the two suggestions above show that the initial state of the Big Bang is not beyond scientific understanding, and that seemingly wildly implausible coincidences may be the result of natural laws at work. This is a point one should bear in mind when considering other alleged examples of fine-tuning.

Fine-tuned for disaster

The fine-tuning is popular among Christian apologists, and they want the universe not only to be fine-tuned for life, but to be fine-tuned for *human* life. It is then relevant to point out that the same constants and initial conditions that have allowed humans to evolve, also ensure that our existence will be a brief episode in the history of the universe. We know, for example, that in a few billion years the Sun will move off the main sequence to become a red giant, destroying life on Earth in the process. And there are several other threats that may exterminate human life long before this happens. It does not seem like the universe has been made with us in mind.

The Rare Earth hypothesis

What is meant by the term “fine tuning” when describing the universe? It can mean several things. It can mean that the universe seems to be set up for us humans to be here. It can mean that the universe seems to be set up for anyone to be able to observe it (which gives a particular privilege to the position of observers). It can mean that the universe seems to be set up for anything complex to happen within it. The main idea is that the universe has the appearance of being “set up”, which implies purpose.

The general idea is that the very fine settings of physical constants are required to allow for the universe we live in.

A supposed example of the tuning of the universe is that the Earth orbits in a narrow band around the Sun – the so-called “Goldilocks Zone”. Only within this zone can liquid water exist on a planet, and allow for the possibility of life. We search nearby stars for planets within their “Goldilocks Zones” in the hope of finding other earths, and other life. Some have suggested that Earth is a very rare planet indeed. Ward and Brownlee published their “rare Earth hypothesis” in a *Rare Earth: Why Complex Life Is Uncommon in the Universe* (2000), suggesting that the Earth is in a series of “Goldilocks” situations, including having a large moon, and being at a certain place in a certain type of galaxy. The idea of the Goldilocks Zone is very persistent, and almost certainly completely wrong when it comes to where liquid water, and so life that we would recognize, can exist.

There have been some amazing findings made by probes in our solar system in recent decades, and especially in recent years. One relevant to the possibility of life is tidal heating within the moons of gas giants. The same forces that lead to the spectacular volcanism on Jupiter's moon Io has almost certainly resulted in a large ocean within other satellites of that planet - Europa, and perhaps Callisto. We have recently seen evidence of water within Iapetus – a smaller moon of Saturn. The volumes of water within these moons are considerable. There is probably more water within Europa than in all the oceans on Earth. The implications are stunning – it may be that the existence of most liquid water in the Universe may have nothing to do with the heat from suns.

It is even possible for planets to have liquid water without tidal or stellar heating. The following situation is described by Ian Stewart and Jack Cohen in ***Evolving the Alien: The Science of Extraterrestrial Life*** (2002). Imagine an Earth-sized planet ejected by near-collision with another body from its solar system. If this happened early on in the lifetime of the solar system the planet may well have retained a thick hydrogen-rich atmosphere. This atmosphere would be a good insulator in the depths of inter-stellar space. Such a good insulator that the surface of such a planet could remain above the freezing point of water for billions of years, purely as a result of heat from radioactive decay within the planet.

We know that on Earth, whenever water is found, there is almost always life, from sub-zero temperatures to well above normal boiling point. If life arises easily, then water-based life is likely to be very widespread indeed throughout the universe. In our own solar system, there may even be a greater volume of life and number of life forms away from our home planet.

The "Goldilocks Zone" idea of the Earth being a possibly unique, or certainly rare, home for life now looks hopelessly outdated, and yet another argument for fine tuning is shown to be deeply mistaken.

Probabilistic considerations

The fine-tuning argument is an inductive argument: the fine-tuning is claimed to be too improbable to have arisen by natural processes, and that the probable explanation therefore is some form of supernatural Fine Tuner. By analyzing the argument we will now show that this does not at all follow. This has been pointed out several times, for example in the article "The anthropic principle does not support supernaturalism" by Michael Ikeda and Bill Jefferys (http://www.talkreason.org/articles/super.cfm).

The main point to be made can be illustrated by an example of the so-called "Prosecutor's fallacy" in probability theory: Imagine a bowl filled with a large but unknown number of balls. The balls are either made of wood or plastic. All the wooden balls are white, while of the plastic balls 99 percent are red and only 1 percent are white. You draw a ball at random, and observe that it is white. Can you calculate the probability that the ball is made of wood with the information given?

The answer is no. It is tempting to conclude that the ball is likely to be made of wood since the probability that a random plastic ball is white is only 0.01, but this is wrong. If, for example, the number of plastic balls is vastly greater than the number of wooden balls, then a random ball is much more likely to be a white plastic ball than a white wooden ball.

The relevance for the fine-tuning argument is hopefully clear. Even if one grants that the values we observe for the natural constants in our universe are unlikely given naturalism, one cannot draw the conclusion that naturalism is unlikely given the fine-tuning. Additional information, for example about the probability of fine-tuning given supernaturalism, is required. For further discussion, see the article “The Design Argument” by Elliott Sober, available at http://www.anthropic-principle.com/preprints.html#design

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The multiverse

It is likely that the universe contains a vast number of planets. Since the first extrasolar planets were discovered a little more than ten years ago, more than 300 have been discovered in our galactic neighbourhood. The sensitivities currently obtainable makes it difficult to detect Earth-like planets, so the huge majority of known extrasolar planets are Jupiter-like giants. However, these discoveries make it seem likely that planetary systems around stars are fairly common, and given that the Milky Way, which is a typical spiral galaxy, has more than 200 billion stars, the number of planets in the observable universe is mind-boggling. Given that life has a non-zero probability of arising, it is not surprising that there is life somewhere within the observable universe. And given the fact that complex organic life most probably cannot evolve in an unfriendly environment like one finds on, say, Jupiter, we should not be surprised to find ourselves inhabiting a medium-sized planet with a decent atmosphere, liquid water etc. In other words, given the kind of universe we live in, it is not a big surprise that we exist, and that we live on an Earth-like planet.

If the fine-tuning is real in the sense that the values of physical constants are improbable and yet determined by natural processes, can it have a similar explanation? The answer is yes, if there exists an ensemble of regions of space-time like our observable universe, and the constants of nature can take on different values in different members of the ensemble. Comparing with the previous paragraph, our observable universe would play the role of Earth, and the other members of the ensemble would be analogous to other planets. If there is a vast ensemble of such space-time regions, we should not be surprised that there is at least one instance of complex organic life in one of them, and the appearance of fine-tuning is simply a result of the fact that complex life can only arise in regions that appear to be fine-tuned.

The big question is whether this scenario is possible and likely given what we know about physics and cosmology, and whether it is a scientific hypothesis. The latter would typically be taken to mean that the so-called multiverse hypothesis should make falsifiable predictions. Note that this does not necessarily mean that the other "universes" need to be directly observable. If the model predicts that some observable feature should be seen in our universe, and it is not seen, the model will be ruled out.

We have several models that provide a basis for such a scenario. Lee Smolin in his book "The Life of the Cosmos" has suggested a model called Cosmological Natural Selection (CNS). He speculates that black holes can give birth to new regions of space-time, causally separated from our universe. These new universes may have slightly different values of the fundamental constants, and each universe gives birth to as many new universes as it has black holes. So a "successful" universe will contain many black holes. The model thus has reproduction and mutation. The hypothetical mechanism for the analogue of natural selection is the fact that universes with no or few black holes will have fewer "offspring".

This model has got some weak points. First of all, it is not at all clear what happens inside a black hole. The solutions of general relativity that describe black holes predict unphysical results at the center of the hole ("singularities"), and to know whether new regions of space-time can be born there, one really needs a singularity-free solution. This will require a quantum theory of gravity. Smolin has played a huge part in the development of one such theory, Loop Quantum Gravity (LQG). LQG has more modest goals than its main competitor, string theory. No attempt is made at a unified theory of all the forces of nature. The goal is simply to quantize gravity in four space-time dimensions. The proponents of LQG have found results that at least do not rule out a universe-generating mechanism, but there is still a long way to go before there is solid science behind Smolin's idea..

Another concern is that for the scenario to work, the "mutations", i.e., the changes in fundamental constants from a parent universe to its daughter, need to be small. Otherwise, there is no guarantee that a universe with many black holes will have equally successful offspring. Since LQG is a theory of gravity alone it cannot say anything about this. We need a quantum theory of all forces, including gravity, in order to work out the model in detail. At present, CNS is an interesting speculation awaiting a detailed theoretical framework. The advantage of the model is that it makes a clear and falsifiable prediction: the parameters of our universe should be optimal for black hole production.

If there is a multiverse, and the natural constants can take on different values in different members, the appearance of fine-tuning is no more mysterious than the fact that we live on earth, and not on Jupiter or Mercury. A common objection from theists is, however, that the multiverse violates Occam's Razor. The fine-tuning is explained by postulating a potentially infinite number of unobservable universes. Isn't the hypothesis of a divine Fine Tuner more parsimonious?

This is not a valid objection. In the multiverse, all the members obey the same underlying laws of physics, and are produced by the same mechanism, probably some variant of the process known as eternal inflation. No new physical principle needs to be postulated. In contrast, the hypothesis of a heavenly Fine Tuner involves several new concepts for which we have no coherent definitions or a working model: a being outside space and time, who is still somehow able to interact with matter, a timeless cause, and an infinitely complex mind without a brain. Parsimony is not one of the divine virtues.

Conclusion

We look back at the past of the universe from a unique perspective. Each of us. No matter what we know, we all feel, in our guts, that Copernicus was wrong. There are 6 billion universes, all centred on planet Earth. As we each look out at our private realities, we feel ourselves at the centre. We turn our heads, and the universe moves around us. This is the illusion we are born with, and we gradually - but rarely completely - grow out of.

Most people never manage to see through the illusion. Around them they see a half-dream world built by an imaginary architect that is itself constructed from and by wishful thinking. It must be a kindly architect as the world is suited to us, and he is made in our image, because what other image do we know?

Fine tuning is an important question. But rarely is it the right question. The wrong question is "why am I here?". The right question is "why is there what we see?" We start to ask the right questions when we look at reality in collaboration with others, when we realise that our personal universe isn't special.

From what we see, we make pretend universes, models that we can feel and shape with mathematics, and fire up into life in computers.

These models audition in front of facts, and the facts come from the most important thing in science - the sample. We have a sample - the reality in which we live.

Do they at least allow us? We aren't special. We may not even be typical. But we are necessary. No model can exclude us. That is the real meaning of "fine tuning" - the tuning need not be fine, but it has to include our wavelength, as our voices are part of reality, broadcast into the universe.