Extending cosmological natural selection

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October 4, 2006

Abstract

The purpose of this paper is to propose an extension to Lee Smolin's hypothesis that our own universe belongs to a population of universes which have evolved by natural selection. Smolin's hypothesis explains why the parameters of physics possess the values we observe them to possess, but depends upon the contingent fact that the universe is a quantum relativistic universe. It is proposed that the prior existence of a quantum relativistic universe can itself be explained by the notion of evolution towards stable ('rigid') mathematical structures.

1 Introduction

According to current mathematical physics, there are many aspects of our physical universe which are contingent rather than necessary. These include such things as the values of the numerous free parameters in the standard model of particle physics, and the parameters which specify the initial conditions in general relativistic models of the universe. The values of these parameters cannot be theoretically derived, and need to be determined by experiment and observation. Study has revealed that the existence of life is very sensitively dependent upon the values of these parameters (Barrow and Tipler 1986). If a universe had values for these parameters only slightly different from the values they possess in our own universe, then that universe would be incapable of supporting life. Hence, people have sought to explain why a life-supporting universe exists.

In fact, the problem posed by the contingent values of the free parameters can be generalised. If our physical universe is conceived to be an instance of a mathematical structure, (i.e., a structured set), then it is natural to ask why this mathematical structure physically exists and not some other. The mathematical structure which our universe physically instantiates is contingent, and requires some explanation.

The problem posed by the free parameters of the standard model is a special case of this because the values chosen for those parameters correspond to a choice of structure at various points in the theory. For example, the coupling constants of the strong and electromagnetic forces, the Weinberg angle, the masses of the elementary quarks and leptons, and the values of the four parameters in the Cabibbo-Kobayashi-Maskawa matrix, (which specifies the 'mixing' of the

$\{d, s, b\}$ quark flavours in weak force interactions), all correspond to a choice of mathematical structure. The values chosen for the coupling constants of a gauge field with gauge group G correspond to a choice of metric in the Lie algebra $\mathfrak{g}$ (Derdzinksi 1992, p114-115); the Weinberg angle corresponds to a choice of metric in the Lie algebra of the electroweak force (ibid., p104-111), and, in combination with the electromagnetic coupling constant, determines the electroweak coupling constants; the values chosen for the masses of the elementary quarks and leptons correspond to the choice of a finite family of irreducible unitary representations of the local space-time symmetry group, from a continuous infinity of alternatives on offer; and the choice of a specific Cabibbo-Kobayashi-Maskawa matrix corresponds to the selection of a specific orthogonal decomposition $\sigma_{d'} \oplus \sigma_{s'} \oplus \sigma_{b'}$ of the fibre bundle which represents a generalisation of the $\{d, s, b\}$ quark flavours (ibid., p160).

One response to this problem of contingency is to postulate the existence of a collection of universes, which realise numerous different mathematical structures, and numerous different values for the parameters of physics. It is common these days to refer to such a collection as a 'multiverse'. Multiverses can be distinguished by whether or not some physical process is suggested to account for their existence. For example, Linde's chaotic inflation theory (1983a and 1983b), and Smolin's theory of cosmological natural selection (1997), both propose physical processes that yield collections of universes or universe-domains. Other multiverse proposals postulate universes which are mutually disjoint, and which are either not the outcome of a common process, or not the outcome of any process at all.

As Tegmark points out, all such proposals which suggest that "some subset of all mathematical structures... is endowed with... physical existence," (1998, p1), fail to explain why some particular collection of mathematical structures is endowed with physical existence rather than another. Tegmark's own response is to suggest that all mathematical structures have physical existence. The weak anthropic principle similarly postulates the existence of a collection of universes which is sufficiently large and varied that the conditions which permit the existence of life will be realised in at least some of the universes. Both types of proposal accept that a life-permitting universe is a highly atypical member of the universe collection, and both types of proposal are difficult, if not impossible, to empirically test. Alternatively, Smolin's proposal of cosmological natural selection explains the existence of our life-supporting universe, renders such universes highly typical, and is subject to empirical test. We now proceed to expound Smolin's hypothesis.

2 Cosmological natural selection

To understand Smolin's idea, it is first useful to appreciate that the conditions for natural selection to occur can be precisely defined, in complete abstraction from any particular physical instance. If a collection of objects satisfies these conditions, then that collection will, with overwhelming likelihood, evolve by natural selection, irrespective of what those objects are. Darwinian biological evolution by natural selection, is just one particular case.

John Barrow asserts that natural selection (or, as he calls it, 'Darwinian evolution'), "has just three requirements:

- The existence of variations among the members of a population. These can be in structure, in function, or in behaviour.
- The likelihood of survival, or of reproduction, depends upon those variations.
- A means of inheriting characteristics must exist, so that there is some correlation between the nature of parents and their offspring. Those variations that contribute to the likelihood of the parents' survival will thus most probably be inherited.

It should be stressed that under these conditions evolution is not an option. If any population has these properties then it must evolve," (Barrow 1995, p21).

Smolin hypothesises that there exists a population[1] of universes, and that the values of the free parameters in the standard model of particle physics are variable characteristics of the universes in the population. For simplicity, let us accept that the values of the fundamental parameters of physics are fixed in each universe, but can vary from one universe to another.

Smolin hypothesises that certain types of universe in the population are reproductively active. He suggests that in those universes where black holes form, a child universe is created inside the event horizon of the black hole. Specifically, Smolin's proposal is that "quantum effects prevent the formation of singularities, at which time starts or stops. If this is true, then time does not end in the centers of black holes, but continues into some new region of space-time... Going back towards the alleged first moment of our universe, we find also that our Big Bang could just be the result of such a bounce in a black hole that formed in some other region of space and time. Presumably, whether this postulate corresponds to reality depends on the details of the quantum theory of gravity. Unfortunately, that theory is not yet complete enough to help us decide the issue," (1997, p93).

In the decade since Smolin proposed his idea, loop quantum gravity has made some significant progress, and its application to cosmology now appears to support Smolin's hypothesis. For example, in a recent review, Ashtekar asserts that "In the distant past, the [quantum] state is peaked on a classical, contracting pre-big-bang branch which closely follows the evolution dictated by Friedmann equations. But when the matter density reaches the Planck regime, quantum geometry effects become significant. Interestingly, they make gravity *repulsive*, not only halting the collapse but turning it around; the quantum state is again peaked on the classical solution now representing the post-big-bang, expanding universe," (2006, p12)

[1]Hereafter, I shall refer to a collection of universes which are related in some way as a 'population' of universes.

Smolin postulates that the reproduction which takes place is reproduction with inheritance. He assumes that "the basic forms of the laws don't change during the bounce, so that the standard model of particle physics describes the world both before and after the bounce. However, I will assume that the parameters of the standard model do change during the bounce," (1997, p94). Smolin postulates that a child universe inherits almost the same values for the parameters of physics as those possessed by its parent. He postulates that the reproduction is not perfect, that small random changes take place in the values of the parameters. Hence, Smolin postulates reproduction with inheritance and mutation. As Shimony puts it, "the variable entities are universes, and the theatre in which the variation occurs is governed by the principles of quantum gravity (as yet not fully constructed) and the form of the standard model," (1999, p217). Smolin's scenario cannot explain why our universe is relativistic rather than non-relativistic, and it cannot explain why our universe is a quantum universe rather than a classical universe, because the occurrence of black holes requires a relativistic universe, and the occurrence of a 'bounce' inside the horizon of a black hole requires a quantum universe.

The number of black holes in a universe is determined by the parameters of physics, hence the values of the parameters in a universe determine the number of children born to that universe. If Smolin's postulate that child universes are created inside black holes with small random parameter mutations is indeed correct, then a population that contains some black hole producing universes, will probably evolve by natural selection. In particular, a population with an exhaustive, initially uniform distribution of parameter value combinations, will come to be dominated by universes that maximise the production of black holes.

In addition to the hypothesis that there is a population of universes evolving by natural selection, Smolin suggests that the parameter values which maximise black hole production, and therefore child universe birthrate, are also the values which permit the existence of life. If the universe types with the highest birthrate are also those universes which permit life, then universes which permit life will come to dominate the population of universes.

The hypothesis that there is a population of universes evolving by natural selection is distinct from the hypothesis that the parameter values which maximise black hole production are the same parameter values which permit life. One hypothesis could be true, and the other false. Only if both are true will life-permitting universes come to dominate the population of universes. If child universes were created inside black holes with small random parameter variations, but the parameter values which maximise black hole production were *not* the same parameter values which permit life, then there would be a population of universes which evolves by natural selection, but in which life-permitting universes do not come to dominate the population.

A weak anthropic principle explanation that imagines a collection of unrelated universes, rather than a population of universes evolving by natural selection, holds that life-permitting universes are *special* members of the collection. In contrast, Smolin's dual proposal that (i) there is a population of universes evolving by natural selection, and that (ii) the parameter values which maximise black hole production are the same parameter values which permit life, holds that life-permitting universes are *typical* members of the collection. In terms of carbon and organic elements, for example, the theory of cosmological natural selection "predicts that our universe has these ingredients for life, not because life is special, but because they are typical of universes found in the collection," (Smolin 1997, p204).

Smolin's hypothesis depends upon the assumption that there is a quantum relativistic universe at the outset. One can ask for an explanation of why there should be such a universe, rather than a universe in which, say, Newtonian gravity governs the large-scale structure of space-time, or in which classical mechanics and classical field theories govern the behaviour of any particles and fields which exist. The existence of a quantum relativistic universe seems to be contingent rather than necessary. There is, therefore, a need to explain the existence of a quantum relativistic universe. A proposal for just such an explanation will be made in the next section.

3 Stable mathematical structures

As a first step to explaining the type of universe population postulated by Smolin, I would like to entertain the following conjecture:

Conjecture 1 *At some level, the structure of our physical universe is a stable mathematical structure.*

A stable ('rigid') mathematical structure is a structure for which any deformation, in some specified class of deformations, merely leads to an isomorphic structure (see Mazur 2004). A deformation is a continuous variation of a structure by means of some parameter(s). Intriguingly, some of the most fundamental structures which describe our universe are, indeed, stable structures (Vilela Mendes 1994). Firstly, whilst the Lie algebra of the inhomogeneous Galilei group, the local symmetry group of Galilean relativity, is an unstable structure, it deforms into a family of Lie algebras, parameterised by the speed of light c, all of which are mutually isomorphic to the Lorentz group, the local space-time symmetry group of general relativity. Secondly, whilst the Lie algebra defined by the Poisson bracket on the space of observables in a classical physical theory is an unstable Lie algebra, it deforms into a family of Lie algebras, parameterised by Planck's constant[2] $\hbar$, all of which are mutually isomorphic to the Lie algebra defined by the commutator on the space of observables in the corresponding quantum theory. If one thinks of each value of $\hbar$ as defining a different quantum theory, then this amounts to the deformation of a classical theory into a family of quantum theories. The same type of deformation can be performed using C*-algebras: "the classical algebra of observables is 'glued' to the family of quantum algebras of observables in such a way that the classical theory literally forms the boundary of the space containing the pertinent quantum theories (one

[2]Strictly, this is the 'reduced' Planck constant, $\hbar = h/2\pi$.

for each value of $\hbar > 0$)," (Landsman 2005, Section 4.3). At least some of the parameters of physics are therefore the deformation parameters of mathematical structures, and a relativistic quantum universe, such as our own, corresponds in at least some respects to a stable structure.

There are also some suggestive facts from the standard model of particle physics, where each gauge force field has an 'internal' symmetry group, called the gauge group. A gauge group must be a compact, connected Lie Group. In our universe, the gauge group of the electromagnetic force is $U(1)$, the gauge group of the electroweak force is $U(2) \cong SU(2) \times U(1)/\mathbb{Z}_2$, and the gauge group of the strong force is $SU(3)$. Now, the vanishing of the second cohomology group of a Lie algebra entails that the Lie algebra is stable (see Vilela Mendes 1994). Semi-simple Lie algebras have a trivial second cohomology group, hence semi-simple Lie algebras are stable structures. Every simple Lie algebra is semi-simple, and $SU(2)$ and $SU(3)$ are simple Lie groups, hence the Lie algebras of $SU(2)$ and $SU(3)$ are stable structures. Moreover, the Lie algebra of $U(1)$ is $\mathbb{R}$, and, as the only 1-dimensional real Lie algebra, this is also a stable Lie algebra.

There are, however, many simple, compact, connected Lie groups. The list of the simply connected ones alone, contains the special unitary groups $SU(n),\ n \geq 2$; the symplectic groups $Sp(n),\ n \geq 2$; the spin groups $Spin(2n+1),\ n \geq 3$; the spin groups $Spin(2n),\ n \geq 4$; and the five exceptional Lie groups E_6, E_7, E_8, F_4, and G_2, (Simon 1996, p151). Hence, structural stability alone can only go so far towards explaining why the gauge fields which exist in our universe are those which have either $U(1)$, $U(2) \cong SU(2) \times U(1)/\mathbb{Z}_2$, or $SU(3)$ as their gauge groups. The gauge fields which exist in our universe might have to be explained by a combination of structural stability and additional constraints on the permissable gauge fields.

To explain why our universe is, at some level, a stable mathematical structure, I would like to make the following proposal:

Conjecture 2 *There is a physical process which randomly changes deformation parameters such as c and $\hbar$.*

Because c and $\hbar$ are parameters with dimensions, this makes it difficult to unambiguously determine, by observation and measurement, whether these parameters actually are subject to variation; the variation of dimensionless parameters is much easier to test (Barrow 2004). Nevertheless, the proposal above constitutes a potentially testable conjecture, and is therefore a scientific conjecture. The existence of such a physical process will inevitably result in a relativistic quantum universe, even if it started with a classical universe, or a non-relativistic universe. Moreover, with the imposition perhaps of further constraints, such a process might produce a universe with gauge fields like our own, even if it started with quite different gauge fields. If so, then a quantum relativistic universe with the gauge force fields we observe, would be a stable region in the mathematical 'landscape'.

However, such a conjecture only goes so far; the mathematical structures which describe our universe can only be cast as stable structures at a quite general level. Whilst a quantum relativistic universe can be said to be a stable structure, the specific structures of the particles and fields in such a universe cannot. For example, recall that the values of the coupling constants of the gauge fields correspond to the choice of particular metrics on the gauge group Lie algebras, and the particular metrics chosen in our own universe are not stable in any sense; different coupling constants correspond to non-isometric structures on the gauge group Lie algebras.

To explain the more detailed mathematical structure of our universe, I would therefore like to propose that we combine the notion of evolution towards stable mathematical structures with Smolin's scenario of cosmological evolution by natural selection. I would like to propose that:

Conjecture 3 *Our universe belongs to a population of quantum relativistic universes, evolving by natural selection.*

To reiterate, Smolin's scenario explains how parameters of the standard model, such as the coupling constants of the gauge fields, come to possess the values we observe. I propose that the evolution of universes which occurs within Smolin's scenario, takes place within a context established by the prior evolution of a stable mathematical structure, at a more general level than the level at which the natural selection process operates. In fact, the evolution of universes in Smolin's scenario is *dependent* upon the prior evolution of a quantum relativistic structure. I propose that there are random processes which deformed the structure of the universe, or a region thereof, into a quantum relativistic universe, and from thereon, the processes postulated in Smolin's evolution by natural selection produced a multiverse of quantum relativistic universes, in which the other mathematical structures we observe were able to evolve.

Of course, there are many different types of random process, so one objection to my proposal is to ask which type of random process is taking place, perhaps which stochastic differential equation the random process provides a solution of, and to ask why this particular type of random process is taking place and not some other. A stochastic process defined, for example, by a uniform probability distribution over the relevant random variables, is a very special type of stochastic process. One could postulate different types of multiverse depending upon the type of random evolution in mathematical structure taking place. This objection could also be made against the random variation of parameters in Smolin's scenario, but because Smolin's scenario is placed within the context of a quantum relativistic universe, he could suggest that the type of stochastic evolution is determined by the rules of quantum gravity. Perhaps this is not a problem at all; perhaps the point about stable structures is that any type of random process will eventually take the parameter values into the stable region. The type of the stochastic process will, however, determine the length of time the parameter values are likely to dwell within the stable region.

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