Cosmological natural selection

Undoubtedly one of the most innovative, stimulating, and infuriating cosmological studies of the 1990s is *The Life of the Cosmos*, by Lee Smolin (b.1955). Among living cosmologists Smolin has few equals in his knowledge of and respect for intellectual history, and in the degree to which he integrates this knowledge with his dazzling but amiable theorizing. For the common reader perhaps the most endearing dimension of Smolin's work is the way in which he harmonizes tough scientific and philosophical exploration with an ingenuous sense of amazement at the wonders of the universe, as in his discussion of what he calls "The Miracle of Stars."

Although many different kinds of elementary particles have been discovered, almost all the matter in the universe is made of four kinds: protons, neutrons, electrons, and neutrinos. These interact via four basic forces: gravity, electromagnetism, and the strong and weak nuclear forces. Each of these forces is characterized by a few numbers. Each has a range, which tells us the distance over which the force can be felt. Then, for each kind of particle and each force there is a number which tells us the strength by which that particle participates in interactions governed by that force. These are called the coupling constants. One of these is the electrical charge, which tells how strongly a particle may interact, or be attracted by, other charged particles. The parameters of the standard model consist primarily of the masses of the particles and these numbers that characterize the four forces.

In order to understand why the existence of stars is so improbable, it helps to know some basic facts about the four different interactions. We may start with gravity, which is the only universal interaction. Every particle, every form of energy, feels its pull. Its range is infinite, which means that although the gravitational force between two bodies falls off with distance, it is never zero, no matter how far apart the two bodies may be. Gravity has another distinguishing feature, which is that it is always attractive. Any two particles in the universe attract each other through the gravitational interaction.

The strength by which any particle is affected by gravity is proportional to its mass. The actual force between two bodies is given by multiplying the two masses together, and then multiplying the result times a universal constant. This constant is called Newton's gravitational constant; it is one of the parameters of the standard model. The most important thing to know about it is that it is a fantastically small number. Its actual value depends on the units we use, as is the case with many physical constants. For elementary particle physics it is natural to take units in which mass is measured by the proton mass. In these units you or
I have a mass of about $10^{28}$, for that is now many protons and neutrons it takes to make a human body. By contrast, in these units the gravitational constant is about $10^{-38}$. This tiny number measures the strength of the gravitational force between two protons.

The incredible smallness of the gravitational constant is one of the mysteries associated with the parameters of particle physics. Suppose we had a theory that explained the basic forces in the universe. That theory would have to produce, out of some calculation, this ridiculous number, $10^{-38}$. How is it that nature is so constructed that one of the key quantities that govern how it works at the fundamental level is so close to zero, but still not zero? This question is one of the most important unsolved mysteries in all of physics.

It may seem strange that a force as weak as gravity plays such an important role on earth and in all the phenomena of astronomy and cosmology. The reason is that, in most circumstances, none of the other forces can act over large distances. For example, in the case of the electrical force, one almost always finds equal numbers of protons and electrons bound together, so that the total charge is zero. This is the reason that most objects, while being composed of enormous numbers of charges, do not attract each other electrically.

Gravity is the only force that is always attractive, which means that it is the only force whose effects must always add, rather than cancel, when one considers aggregates of matter. Thus, when one comes to bodies composed of enormous numbers of particles, such as planets or stars, the tiny gravitational attractions of each of the particles add up and dominate the situation.

The incredible weakness of the gravitational constant turns out to be necessary for the existence of stars. Roughly speaking, this is because the weaker gravity is, the more protons must be piled on top of each other before the pressure in the center is strong enough that the nuclear reactions ignite. As a result, the number of atoms necessary to make a star turns out to grow as the gravitational constant decreases. Stars are so huge exactly because the gravitational constant is so tiny.

It is fortunate for us that stars are so enormous, because this allows them to burn for billions of years. The more fuel a star contains, the longer it can produce energy through nuclear fusion. As a result, a typical star lives for a long time, about ten billion years.

Were the gravitational force somewhat stronger than it actually is, stars would still exist, but they would be much smaller, and they would burn out very much faster. The effect is quite dramatic. If the gravitational force were stronger by only a factor of ten, the lifetime of a typical star would decrease from about ten billion years to the order of ten million years. If its strength were increased by still another factor of ten, making the gravitational force between two protons still an effect of order of one part in $10^{36}$, the lifetime of a star would shrink to ten thousand years.

But the existence of stars requires not only that the gravitational force be incredibly weak. Stars burn through nuclear reactions that fuse protons and neutrons into a succession of more and more massive nuclei. For these processes to take place, protons and neutrons must be able to stick together, creating a large number of different kinds of atomic nuclei. For this to happen, it turns out that the actual values of the masses of the elementary particles must be chosen very delicately. Other parameters, such as those that determine the strengths of the different forces, must also be carefully tuned.

Let us think of the three most familiar particles: the proton, neutron, and electron. The neutron, it turns out, has almost the same mass as the proton; it is in fact just slightly heavier, by about two parts in a thousand. In contrast, the electron is much lighter than either; it is about eighteen hundred times lighter than the proton.
In the masses of these three particles there are many mysteries. Why are the neutron and proton so close in mass? Why is the electron so much lighter than the other two particles? But what is most mysterious is that the two small numbers in this problem, the electron mass and the tiny amount by which a neutron is just slightly more massive than a proton, are comparable to each other. The neutron outweighs the proton by only about three electron masses.

We are so used to the idea that protons and neutrons stick together to make hundreds of different stable nuclei, that it is difficult to think of this as an unusual circumstance. But in fact it is. Were the electron's mass not about the same as the amount that the neutron outweighs the proton, and were each of these not much smaller than the proton's mass, it would be impossible for nuclei to stick together to form stable nuclei. These are then facts of great importance for the world as we know it, for without the many different stable nuclei, there would be no nuclear or atomic physics, no stars, and no chemistry. Such a world would be dramatically uninteresting. . . .

While we are discussing physical constants that must be finely tuned for the universe to contain stars, we may consider another kind of question. Why is the universe big enough that there is room for stars? Why is it not much smaller, perhaps even smaller than an atom? And why does the universe live for billions of years, which is long enough for stars to form? Why should it not instead live just a few seconds? These may seem silly questions, but they are not, because the fact that the universe can become very big and very old depends on a particular parameter of the standard model being extremely tiny. This parameter is called the cosmological constant.

The cosmological constant can be understood as measuring a certain intrinsic density of mass or energy, associated with empty space. That a volume of empty space might itself have mass is a possibility allowed by Einstein's general theory of relativity. If this were sizable, it would be felt by matter, and this would affect the evolution of the universe as a whole. For example, were there enough of it, the whole universe would quickly pull together and collapse gravitationally, as a dead star collapses to a black hole. In order that this not happen, the mass associated with the cosmological constant must be much smaller than any of the masses we have so far mentioned. In units of the proton mass, it can be no larger than about $10^{-40}$. If this were not the case, the universe would not live long enough to produce stars. . . .

Perhaps the reader is still not convinced that there is something incredible to be understood here. Let me then go on. We have only discussed gravity; there are three more interactions to consider. These forces are described by still additional parameters. The story for many of these is the same.

We may consider next the force which is most evident in our lives, . . . electromagnetism and light.

The importance of electromagnetism for our modern picture of nature cannot be overstated, as almost all of the phenomena of everyday life which are not due to gravity are manifestations of it. For example, all chemistry is an aspect of electromagnetism. This is because chemical reactions involve rearrangements of electrons in their orbits around atomic nuclei, and it is the electrical force that holds the electrons in those orbits. Light is also an aspect of electromagnetism, for it is a wave traveling through the fields that convey the electric and magnetic forces.

Electromagnetism differs in two important respects from gravity. The first is that electrical force between two fundamental particles is much stronger than their gravitational attraction. The strength of the electrical interaction is measured by a number, which was
called alpha by the physicists of the [nineteenth] century, because it is a number of the first importance to science. Alpha, which is essentially a measure of the strength of the electric force between two protons or electrons, has a value of approximately 1/137. Physicists have been wondering about why alpha has this value, without resolution, for the whole of the twentieth century.

The second way in which electricity differs from gravity is that its effect is not only attractive: two electrical charges may attract or repel each other, depending on whether they are alike or unlike.

As we did for gravity, we may ask how important the existence of a force with these properties is for the existence of stars. Light does, indeed, do something essential for stars. For it must be possible for the energy produced in stars to be carried away to great distances. Otherwise, stars could not radiate, and being unable to get rid of the energy they produce, they would simply explode. Light is precisely the medium by which the energy produced in stars is conveyed to the rest of the universe.

However, the existence of electrical forces makes another problem for stars. Like charges repel, and the nucleus of most atoms contains a number of protons, all of like charge, which are packed closely together. What keeps the nuclei from being blown apart by the repulsion of all the protons in them?

There is no way either electricity or gravity could save the situation. What is needed if nuclei are to exist is another force with certain properties. It must act attractively among protons and neutrons, in order to hold the atomic nuclei together. It must be strong enough to counteract the repulsions of all the protons. But it cannot be too strong, otherwise it would be too difficult to break the nuclei apart, and chain reactions of nuclear reactions could not take place inside of stars.

This force must also be short-ranged, otherwise there would be danger of its pulling all the protons and neutrons in the world together into one big nucleus. For the same reason, it cannot act on electrons, otherwise it would pull them into the nuclei, making molecules and chemistry impossible.

It turns out that there is a force with exactly these required properties. It is called the strong nuclear force, and it acts, as it should, only over a range which is more or less equal to the size of an atomic nucleus.

Remarkably, the existence of more than a hundred kinds of stable nuclei is due to the fact that the strength of the attractive nuclear force balances quite well the electrical repulsion of the protons. To see this, it is necessary only to ask how much we have to increase the strength of the electrical force, or decrease the strength of the nuclear force, before no nuclei are stable. The answer is not much. If the strong interaction were only 50% weaker, the electrical repulsion is no longer overcome, and most nuclei become unstable. Going a bit further, perhaps to 25%, all nuclei fall apart. The same effect can also be achieved by holding the strong interaction unchanged and increasing the strength of the electrical repulsions by no more than a factor of about ten.

Thus we see that the simple existence of many species of nuclei, and hence the possibility of a world with the complexity of ours, with many different types of molecules each with distinct chemical properties, is ultimately the result of a rather delicate balance between two of the basic interactions, the electromagnetic and strong nuclear force.

There is, finally, one more basic interaction, which is called the weak nuclear interaction. It is called a nuclear interaction because the scale over which it can act is also about the size of the atomic nucleus. But it is much weaker than the strong nuclear force. It is too weak to play any role binding things together, but it does play an important role in
transforming particles into each other. It is this weak interaction that governs the basic nuclear reaction on which the physics of stars is based, by means of which an electron and a proton are transformed into a neutron and a neutrino.

The reader to whom these things are new might pause and ponder the characteristics of these four basic forces, for it is they that give our world its basic shape. With their different properties, they work together to allow a world that is both complex and harmonious. Eliminate any one, or change its range or strength, and the universe around us will evaporate instantly and a vastly different world will come into being.

Would any of these other worlds contain stars? How many could contain life? The answer to both of these questions, as we have seen, is not many.

Physicists are constantly talking about how simple nature is. Indeed, the laws of nature are very simple, and as we come to understand them better they are getting simpler. But, in fact, nature is not simple. To see this, all we need to do is to compare our actual universe to an imagined one that really is simple. Imagine, for example, a homogeneous gas of neutrons, filling the universe at some constant temperature and density. That would be simple. Compared to that possibility, our universe is extraordinarily complex and varied!

Now, what is really interesting about this situation is that while the laws of nature are simple, there is a clear sense in which we can say that these laws are also characterized by a lot of variety. There are only four fundamental forces, but they differ dramatically in their ranges and interaction strengths. Most things in the world are made of only four stable particles: protons, neutrons, electrons, and neutrinos; but they have a very large range of masses, and each interacts with a different mix of the four forces.

The simple observation we have made here is that the variety we see in the universe around us is to a great extent a consequence of this variety in the fundamental forces and particles. That is to say, the mystery of why there is such variety in the laws of physics is essentially tied to the question of why the laws of physics allow such a variety of structures in the universe.

If we are to genuinely understand our universe, these relations between the structures on large scales and the elementary particles must be understood as being something other than coincidence. We must understand how it came to be that the parameters that govern the elementary particles and their interactions are tuned and balanced in such a way that a universe of such variety and complexity arises.

Of course, it is always possible that this is just coincidence. Perhaps before going further we should ask just how probable is it that a universe created by randomly choosing the parameters will contain stars. Given what we have already said, it is simple to estimate this probability. . . . The answer, in round numbers, comes to about one chance in $10^{229}$.

To illustrate how truly ridiculous this number is, we might note that the part of the universe we can see from earth contains about $10^{22}$ stars which together contain about $10^{80}$ protons and neutrons. These numbers are gigantic, but they are infinitesimal compared to $10^{229}$. In my opinion, a probability this tiny is not something we can let go unexplained. Luck will certainly not do here; we need some rational explanation of how something this unlikely turned out to be the case.

I know of three directions in which we might search for the reason why the parameters are tuned to such unlikely values. The first is towards some version of the 

**anthropic principle.** One may say that one believes that there is a god who created the world in this way, so there would arise rational creatures who would love him. We may even imagine that he prefers our love of him to be a rational choice made after we understand how
unlikely our own existence is. While there is little I can say against religious faith, one must recognize that this is mysticism, in the sense that it makes the answers to scientific questions dependent on a faith about something outside the domain of rationality.

A different form of the anthropic principle begins with the hypothesis that there are a very large number of universes. In each the parameters are chosen randomly. If there are at least \(10^{229}\) of them it becomes probable that at least one of them will by chance contain stars. The problem with this is that it makes it possible to explain almost anything, for among the universes one can find most of the other equally unlikely possibilities. To argue this way is not to reason; it is simply to give up looking for a rational explanation. Had this kind of reasoning been applied to biology, the principle of natural selection would never have been found.

A second approach to explaining the parameters is the hypothesis that there is only a single unique mathematically consistent theory of the whole universe. If that theory were found, we would simply have no choice but to accept it as the explanation. But imagine what sense we could then make of our existence in the world. It strains credulity to imagine that mathematical consistency could be the sole reason for the parameters to have the extraordinarily unlikely values that result in a world with stars and life. If in the end mathematics alone wins us our one chance in \(10^{229}\) we would have little choice but to become mystics. This would be an even purer mysticism than the anthropic principle because then even God would have had no choice in the creation of the world.

The only other possibility is much more mundane than these. It is that the parameters may actually change in time, according to some unknown physical processes. The values they take may then be the result of real physical processes that happened sometime in our past. This would take us outside the boundaries of the platonist philosophy, but it seems nevertheless to be our best hope for a completely rational understanding of the universe, one that doesn't rely on faith or mysticism. [37-46]

Smolin does not define faith or mysticism with the rigor he applies in other areas. Nevertheless, in his effort to avoid them and to find a purely naturalistic (he would say rational) explanation for this astonishingly unlikely universe, he turns to a possibility that may get around the need to assume that the universe came from nothing. This possibility is that black holes are "locations" for new big bangs. But first, in his informative way, he explains another amazing cosmic conundrum related to the early universe.

Imagine for a moment that you could see the cosmic black body radiation. You look up at the sky and see a flash of light from a photon that has traveled around ten billion years, from the time of decoupling [the early phase transition at which the early stuff of the universe ceased to be opaque plasma] to your eye. Now, turn your head a few degrees to the right, and wait again for a photon from the black body radiation to come to your eye. Coming to us from different directions, and traveling for such a long time, these two photons come from regions of the universe that were very far apart when they were created. Even taking into account the fact that the universe has expanded a great deal (about a thousand fold) while they were traveling, it is still true that they were very far apart when they began their journeys.

What is remarkable is that, even if they started out from regions of the universe that were very far apart, all of the photons coming from the time the universe was opaque tell the same story. To an accuracy of about one part in a hundred thousand, the temperature at that time seems to have been the same all over the universe.
This is one of the big mysteries of modern cosmology. How is it possible that regions of the universe that were very far apart at that time had, nevertheless, almost precisely the same temperature? Questions like this are usually not hard to answer. We know that a glass of hot water left in a room will eventually cool to the temperature of the room. As a result of the tendency of things to come to equilibrium, when things are in contact for long enough they tend to come to the same temperature. The simplest possibility is then that all the different regions of the universe had been in contact with each other before the moment of decoupling.

Unfortunately, if we believe in the story of cosmology given by general relativity, this cannot have been the case. As the universe is supposed to have been only about a million years old at the time of decoupling, and as nothing can travel faster than light, only regions that were then less than a million light years apart could have had any contact with each other. The problem is that, according to the theory, the universe at this time was much bigger than a million light years across. This means that when we detect the cosmic background radiation coming from two different points in the sky more than a few degrees apart, we are seeing light that originated from regions that up till that time could not have had any kind of contact with each other.

To emphasize how strange this is, let us suppose that the signal of the cosmic background radiation was modulated like a radio broadcast. And let us suppose that, from every corner of the universe, the tune played by the cosmic background radiation was rock 'n' roll, and not only rock 'n' roll, but the same Cosmic Top Ten: The Beatles, Madonna, Bruce Springstein, Gianna Nannini, etc. How could we account for this? It would be no problem if the different regions had been able to listen to each other, for the appeal of good music (or, if the reader prefers, the economics of cultural penetration) is almost as absolute as the laws of thermodynamics. Indeed, we are not surprised to hear the same music in every restaurant and bar on this planet. But what if the different regions could never have been in contact with each other? It would be as if Hernan Cortes, arriving in the court of Montezuma, heard around him only the songs he had learned in the taverns of Seville. We would then have to believe in a miracle of a thousand simultaneous births of rock 'n' roll, a thousand simultaneous Memphises and Detroits, each totally unaware of the others.

This may seem ridiculous, but it is not much more ridiculous than what is actually seen: many regions which, if we believe the standard theory, could never have been in contact with each other, but in which the temperatures are the same, to fantastic precision. The reader may be confused by this. Isn't the idea of the "Big Bang" that the whole universe expanded from a point? This is the popular conception, but it is not actually what general relativity says. It is true that if we trace back the history of any particle, we find an initial singularity at which the density of matter becomes infinite. However, what is not true is that all the particles in the universe meet at their first, singular moments. They do not. Instead, they all seem to spring into existence, simultaneously but separately, at the same instant. Just after the first instant of time, the universe already has a finite spatial extent. One million years later, the universe is much larger than one million light years across, leading to the problem we have been discussing.

Of course, it is always possible that all the different regions of the universe were created, separately, with exactly the same conditions. The different regions had the same temperature a million years later, because they were created with the same temperature. This may seem to resolve the question, but it only leaves a different mystery: Why were all the regions created with exactly the same conditions? This does not solve the problem; it only
makes it worse by forcing us to imagine that whatever created the universe did it in a way that duplicated the same conditions in an enormous number of separate regions.

Indeed, as long as we believe that the world was born a finite time ago, we have the problem of explaining what the conditions were at the moment of creation. Whether the temperatures were the same everywhere, or whether the pattern of hot spots spelled out "Made in Heaven," we would have the same problem of explaining what the conditions were at the moment of creation.

One escape from this dilemma would be if general relativity were wrong about the early history of the universe. We have already noted that this is quite possible, given that general relativity does not take into account the effects of quantum physics. There are indeed at least two ways that quantum effects might win the universe enough time. The first is called the hypothesis of cosmological inflation. The idea is that as the universe expands and cools, it makes a transition between different phases . . . . This transition may have occurred very early in the history of the universe only a fraction of a second after its creation. According to the hypothesis, before the transition the universe was in a phase in which it expanded much more rapidly than it does in its present state. This is called a period of inflation, to contrast it with the present period in which the expansion is much slower. During inflation the universe may double in size every $10^{-35}$ of a second or so. Because of this, regions of the universe that are now billions of light years apart were initially very, very close to each other. As a result, it becomes possible for all the regions of the universe we can see to have been in contact with each other in the time since its beginning.

The hypothesis of cosmological inflation turns out to have one basic problem, which is that it requires several careful tunings of the parameters of particle physics. This is necessary not to make inflation happen, but instead to make sure that it stops. It is as if the Federal Reserve Board were trying to tune the interest rates now in order to prevent rapid inflation, not only before the next election, but for the next ten billion years. Perhaps they might then be talking about changes in interest rates of a millionth of a percent, which is at least as finely as the parameters in the theory of inflation must be chosen so that the period of rapid expansion lasts only for a very limited time.

Of course, this is only one more problem in which some parameter must be chosen very delicately if the universe is to be as we find it. As it is far from the only one, this cannot be held against the hypothesis of cosmological inflation. If there were a mechanism to tune the proton mass or the cosmological constant to incredibly tiny numbers, it could possibly do the same for the parameters that determine how long cosmological inflation lasts. What is certain is that if . . . quantum mechanics does not get rid of the singularity in our past, then inflation seems necessary to explain why the whole universe seems to have been at the same temperature at the moment of first transparency, only a million years after the first moment of time.

But there is a second possibility, which is that quantum effects might completely eradicate the singularity. In this case there would be no moment of creation. Time would instead stretch indefinitely far into the past. Regardless of inflation, there would have been enough time for all the regions of the universe to come into contact. This would not mean that cosmological inflation is wrong, for there are other reasons one might want to consider it. But in this case we have to ask what happened in the world before the "Big Bang." That term would no longer refer to a moment of creation, but only to some dramatic event that led to the expansion of our region of the universe. In this situation it becomes possible to ask if there were processes which acted before the "Big Bang" to choose the parameters of elementary particle physics. [82-85]
This last sentence gives the clue to the rest of Smolin's thesis, his radical idea that processes--ones analogous to those of Darwinian evolution--account for the emergence of "species" of universes fit for survival and complexity. From another angle, however, we may also see Smolin's project as something like a conflation of the Big Bang and Steady State theories, with a multiplicity of big bangs--a continuous production of universes--akin to Hoyle's "continuous creation" of matter to replenish the cosmos (chap. 000). And we can also see a similar motivation operating in the case of both Hoyle and Smolin: a desire to avoid at any cost the notion of a radical beginning.

Smolin continues his discussion, pursuing the issue of boundaries, including the crucial role he sees for black holes as locations for the coming to be of new universes. In this he continues a familiar pattern in the history of cosmology, namely the "pluralizing" of a concept that initially did not admit of a plural: from earth to "earths"; from sun to "suns"; from the galaxy to "galaxies"; and now, in Smolin, from the universe to "universes."

If we assume that Einstein's general theory of relativity gives a correct description of what happens to a collapsing star, then it is quite certain that what lies inside of each black hole is a singularity. This is in fact exactly what Roger Penrose proved when he found the first of the theorems about singularities.

There is an important difference from the case of the cosmological singularity, which is that in a black hole the singularity lies in the future rather than in the past. According to general relativity every bit of the collapsed star and every particle that falls afterwards into the black hole will end up at a last moment of time, at which the density of matter and strength of the gravitational field become infinite.

However, we do not trust general relativity to give us the whole story about what happens inside a black hole, for the same reason we don't trust it in the cosmological case. As the star is squeezed towards infinite density, it must pass a point at which it has been squeezed so small that effects coming from quantum mechanics are at least as important as the gravitational force squeezing the star. Whether there is a real singularity is then a question that only a theory of quantum gravity can answer.

Many people who work on quantum gravity have faith that the quantum theory will rescue us from the singularities. If so, it may be that time does not come to an end inside of each black hole. At present, despite several very interesting arguments that have recently been invented, the question of what happens inside of a black hole when quantum effects are taken into account remains unresolved.

If time ends, then there is literally nothing more to say. But what if it doesn't? Suppose that the singularity is avoided, and time goes on forever inside of a black hole. What then happens to the star that collapsed to form the black hole? As it is forever beyond the horizon, we can never see what is going on there. But if time does not end, then there is something there, happening. The question is, What?

This is very like the question about what happened "before the Big Bang" in the event that quantum effects allow time to extend indefinitely into the past. There is indeed a very appealing answer to both of these questions, which is that each answers the other. A collapsing star forms a black hole, within which it is compressed to a very dense state. The universe began in a similarly very dense state from which it expands. Is it possible that these are one and the same dense state? That is, is it possible that what is beyond the horizon of a black hole is the beginning of another universe?
This could happen if the collapsing star exploded once it reached a very dense state, but after the black hole horizon had formed around it. If we look from outside of the horizon of the black hole we will never see the explosion, for it lies beyond the range of what we can see. The outside of the black hole is the same, whether or not such an explosion happens inside of it. But suppose we do go inside, and somehow survive the compression down to extremely high density. At a certain point there is an explosion, which has the effect of reversing the collapse of the matter from the star, leading to an expansion. If we survived this also, we would seem to be in a region of the universe in which everything was moving away from each other. It would indeed resemble the early stages of our expanding universe.

This expanding region may then develop much like our own universe. It may first of all go through a period of inflation and become very big. If conditions develop suitably, galaxies and stars may form, so that in time this new "universe" may become a copy of our world. Long after this, intelligent beings may evolve who, looking back, might be tempted to believe that they lived in a universe that was born in an infinitely dense singularity, before which there was no time. But in reality they would be living in a new region of space and time created by an explosion following the collapse of a star to a black hole in our part of the universe.

The idea that a singularity in the future would be avoided by such an explosion is very old; it goes back to the 1930s, long before the idea of a black hole was invented. At this time cosmologists worried about the fate of a universe that neared its final moment of time after expanding and then recontracting. Several cosmologists speculated that we live in what they called a "Phoenix universe," which repeatedly expands and collapses, exploding again each time it becomes sufficiently dense. Such a cosmic explosion was called a "bounce," as the repeated expansions and contractions of the universe are analogous to a bouncing ball.

What we are doing is applying this bounce hypothesis, not to the universe as a whole, but to every black hole in it. If this is true, then we live not in a single universe, which is eternally passing through the same recurring cycle of collapse and rebirth. We live instead in a continually growing community of "universes," each one of which is born form an explosion following the collapse of a star to a black hole.

Recall that we wanted there to be boundaries in the past of our visible universe, when processes might have happened that could somehow choose the laws of physics, or at least select the values of their parameters. What we have learned . . . is that almost inevitably, the existence of such boundaries follows given only the simplest ideas about light and gravity and the basic fact that we live in an expanding universe. Furthermore, we have learned that if we accept the hypothesis that quantum effects eliminate the singularity at the beginning of the universe, and eliminate as well the singularities inside of black holes, we have the possibility that what lies beyond the boundaries is much vaster than our own visible universe.

Smolin leaves his reader, the non-scientist reader at least, worrying that his cosmology is in some sense deeply circular. If we need an evolutionary process of "cosmological natural selection," [p.184] with a multiplicity of new universes big-banging themselves into existence within black holes, in order to come up with the improbably complex sort of universe which we observe--in particular one that has beaten the \(10^{229}\)-to-one odds against there being stars; and if black holes are themselves collapsed stars--then doesn't Smolin's argument presuppose the existence of the very things his thesis sets out to account for?
The other major uneasiness his reader is left with is this: part of Smolin's critique of other physical theories of the universe, particularly those that invoke some timeless fundamental theory, centers on his charge that they involve "nostalgia for the absolute." Yet in its own way Smolin's thought may itself seem tinged with a kind of nostalgia. In the end, his startling if touching metaphor for the universe is not the Lake District in England or Mont Blanc in the Alps, but his own American home town, New York City. Smolin's cosmology, in short, emerges as an evocative if uneasy confluence of the Big Bang and the Big Apple.

For reasons that I thought were quite irrelevant to its content I was drawn to finish this book here, in the greatest city of the planet, my first home. A few weeks ago I took a walk around, looking for a metaphor with which to end this book, a metaphor of the universe constructed, not by a clockmaker standing outside of it but by its elements in a process of evolution, of perhaps negotiation. All of a sudden I realized what I am doing here; for, in its endless diversity and variety, what I love about the city is exactly the way it mirrors the image of the cosmos I have been struggling to bring into focus. The city is the model; it has been all around me, all the time.

Thus the metaphor of the universe we are trying now to imagine, which I would like to set against the picture of the universe as a clock, is an image of the universe as a city, as an endless negotiation, an endless construction of the new out of the old. No one made the city; there is no city-maker, as there is a clock-maker. If a city can make itself, without a maker, why can the same not be true of the universe?

Further, a city is a place where novelty may emerge without violence, where we might imagine a continual process of improvement without revolution, and in which we need respect nothing higher than ourselves, but are continually confronted with each other as the makers of our shared world. We all made it or no one did; we are of it, and to be of it and to be one of its makers is the same thing.

So there never was a God, no pilot who made the world by imposing order on chaos and who remains outside, watching and proscribing. And Nietzsche now also is dead. The eternal return, the eternal heat death, are no longer threats; they will never come, nor will heaven. The world will always be here, and it will always be different, more varied, more interesting, more alive, but still always the world in all its complexity and incompleteness. There is nothing behind it, no absolute or platonic world to transcend it. All there is of Nature is what is around us. All there is of Being is relations among real, sensible things. All we have of natural law is a world that has made itself. [299]