The Deep And Suggestive Principles of Leibnizian Philosophy

By Julian Barbour

1. Introduction

The most obvious thing about the universe in which we find ourselves is its structure. Before the scientific revolution, the instinctive reaction of thinkers to the existence of perceived structure was to find a direct reason for that structure. This is reflected above all in the Pythagorean notion of the well-ordered cosmos: the cosmos has the structure it does because that is the best structure it could have. In fact, that is what the word *cosmos* really means—primarily *order*, but also *decoration*, *embellishment*, or *dress* (*cosmetic* has the same origin). Kepler and Galileo were no less entranced by the beauty of the world than was Pythagoras, and they formulated their ideas in the overall conceptual framework of the well-ordered cosmos. However, both studied the world so intently that they actually identified aspects of motion (precise laws of planetary motion and simple laws of falling bodies and projectiles) that fairly soon led to the complete overthrow of such a notion of cosmos. The laws of the new physics were found to determine not the actual structure of the universe, but the way in which structure changes from instant to instant. Ultimately, no explanation is provided for the currently observed structure; it is simply attributed to an initial structure that was never *fashioned* by the laws of nature but merely continually *refashioned* thereafter. The initial and boundary conditions for our universe lie outside the purview of science. But all of the structure we observe around us must ultimately be traced back to those mysterious initial and boundary conditions.

It is true that very often it does seem as if we possess laws that directly determine structure. A first example is Darwinian evolution;[1] another is the dynamical self-organization of structure;[2] and a third is the way structure emerges from the inflationary scenario in modern cosmology.[3] However, the decisive common feature in all these cases is a very special initial

Julian Barbour is a theoretical physicist and author of The Discovery of Dynamics, *on the historical development of ideas about time and motion, and, more recently,* The End of Time: The Next Revolution in Our Understanding of the Universe. *He has been working on foundational issues in physics—in particular, the nature of time and the origin of inertia—for 40 years. Although he works closely with the Faculty of the Philosophy of Physics at Oxford University, he has been independent throughout his research career.*

condition, which is highly ordered and far from thermal equilibrium; this point is well brought out by Albrecht. Penrose has graphically illustrated the incredible improbability of such a highly ordered state arising by chance by depicting the creative divinity with a pin trying to locate the correct initial point in the space of initial states of the universe.[4] One cannot help wondering if modern science does not lack a key idea. Could there be some direct *structure-creating principle* that has hitherto escaped us?

A further reason for seriously entertaining this idea comes from the so-called "problem of time" in modern attempts to create a quantum theory of gravity. Such a theory of gravity would simultaneously be a quantum theory of the entire universe. However, the highly flexible and relational manner in which time is treated in Einstein's theory of gravity is extremely difficult to reconcile with the role that time plays in quantum mechanics, since in the latter, time is essentially the external, absolute time that Newton introduced. In fact, some researchers in the field doubt whether time has any role at all to play in quantum cosmology, arguing that time is an emergent phenomenon. I find the arguments for this view strong, if not yet decisive, and some years ago published a book, *The End of Time*, suggesting that the next revolution in physics could well be the complete disappearance of time as an essential part of the structure of the universe.[5] Recent research in which I have been involved strengthens me in this belief.[6] This question mark over the very existence of time makes it even more pertinent to seek a structure-creating first principle, since one clearly cannot attribute structure observed in the here and now to "initial" conditions if there is no sense at all in which one can speak about past and future but only "elsewhere."

I would like to suggest that, in this connection, it could be helpful to take a deeper look at the implications of Leibniz's philosophy. In fact, Leibnizian ideas crop up both explicitly and implicitly in many discussions of the conceptual problems of quantum gravity. For the most part they center on the notion of Leibnizian equivalence,[7] which amounts to the proposition that two seemingly distinct situations that are observationally indistinguishable are to be treated as identical. This is Leibniz's principle of the identity of indiscernibles. This and his principle of sufficient reason form the twin pillars of his philosophy—his two "great principles," as he called them. They appeared prominently in his famous controversy with Clarke in 1715–1716 about the foundations of natural philosophy, in which Leibniz critiqued Newton's concepts of absolute space and time.[8] (Clarke was "tutored" in his responses by Newton.) To counter Newton's notion of a preexisting absolute space in which all points are exactly identical, Leibniz claimed that such a situation would have presented God with an impossible decision—where precisely to place the contents of the universe. Why here rather than there? Leibniz argued that even God must have a sufficient reason for all His acts, and the impossibility of finding any such reason for any particular placement demonstrated that the notion of an absolute place could not be correct. Absolute space could not exist, and position must be relative. Space, argued Leibniz, is nothing more than the order of coexisting things, which are "placed" solely by their positions relative to each other.

Unfortunately, Leibniz's intuitions regarding the needs of a dynamical theory were not as acute as Newton's. He failed to come to grips with Newton's dynamical arguments for absolute space. I have argued elsewhere[9] that it is possible to take on Newton's arguments effectively at the level of dynamics, but this is not what I should like to write about here. The point is that Leibniz's two great principles do not really give one an idea of quite how radical his philosophy is; potentially, his philosophy can have implications stretching far beyond his two normative principles. I believe that it does contain the seeds of a structure-creating first principle—and much more. This is what I want to explain. However, I do not in any way want to diminish the value of the two great principles. If you read through Einstein's papers in which he battled his way to the creation of his general theory of relativity, you will see that the spur that kept him going was, in fact, the principle of sufficient reason. Indeed, he carried on directly from where Leibniz was forced by his untimely death to leave the issue. As Einstein never ceased to point out, Newton's use of absolute space was tantamount, in modern terms, to the introduction of distinguished frames of reference (for the formulation of the laws of nature) under conditions in which it was completely impossible to find any reason why they should be distinguished. Einstein found this to be an affront to the principle of sufficient reason, and was therefore led to say that no such distinguished frames of reference can exist, or, rather, that all conceivable frames must be equally good for the formulation of the laws of nature. This was his principle of general relativity—and what a harvest it eventually yielded.

That, I think, is enough justification for taking Leibniz seriously. In the next section, I give a brief summary of what I take to be the most exciting and radical elements of Leibniz's philosophy. Then I present a model in which nontrivial structure is created as a first principle. In the final section, I comment on the Leibnizian aspects of such a model.

2. Variety Opposed to Uniformity

Leibniz developed what to many is a quite fantastical philosophy. To me, however, his philosophy is the one radical alternative to Cartesian-Newtonian materialism ever put forward that possesses enough definiteness to be cast in mathematical form—and hence to serve as a potential framework for natural science. To a large degree, he developed it in response to Descartes, who had sought to account for the phenomenal world with the absolute minimum of concepts.[10] If these were crystal clear, then surely we must intuit them directly by a capacity given to us by God, who would not deceive us in such fundamental matters. Ruminating along these lines, Descartes concluded that the material world consisted of just one single solitary substance with just one distinguishing attribute: extension. He argued further that this extended substance, matter, was divided into pieces that constantly moved relative to each other. Out of this higgledy-piggledy jostling, all the phenomena of nature must arise. This idea was a powerful stimulus to the mechanical model of the universe that was developed in the 17th century, according to which the material world consists of infinitely many essentially identical indivisible atoms in constant motion. This is reductionism in its classic form.

In his youth, Leibniz was “infected” by this idea, as he often remarked later, yet he found what seems to be a serious flaw in Descartes’s windswept ontology. If matter has but one distinguishing attribute, extension, how do we come to see *anything*? There are no attributes to distinguish one piece of matter from another. There is nothing in this scheme to explain the *variety of the world*. At the very least, Descartes would have needed to postulate a second attribute, probably more. It is interesting that, broadly, this is the route that was taken by physics, though founded on a much more secure empirical basis than Descartes had deemed necessary. Through much of the last century, one of the main goals of physics was to find the fundamental particles of nature. Even at the time when quantum mechanics was discovered, in 1925–1926, physicists believed that all matter was composed of only two fundamental particles—the electron and the proton. This picture does indeed look like a minimal extension of Cartesian reductionism. But during the course of the century, the number of so-called fundamental particles grew in a somewhat disconcerting manner, though our understanding of the way in which they interacted also progressed impressively. Now, if the superstring enthusiasts are correct, we are almost back to Descartes—all the phenomena of nature are to be understood as manifestations of submicroscopic strings that wiggle in an 11-dimensional space-time.

Leibniz, in contrast to Descartes, struck out in a very different direction. Like Descartes, he accepted that the universe consisted of infinitely many entities. However, these entities, which he called ‘monads’, were quite unlike atoms, which were always assumed to have identical properties. There might be several different kinds of atoms, but within each class all atoms were assumed to be identical. The only difference between them would be their positions and speeds in space and time. But Leibniz denied the independent existence of space and time. They were nothing but relations between things. Position in space and time could not be used as attributes to distinguish otherwise indistinguishable objects. I find this position very persuasive. The core of Leibniz’s philosophy is the insistence on a proper *principle of individuation*. He argued that any contingently existing thing must be described by its attributes.[11] He then noted that one could never adequately distinguish a given thing by a finite set of attributes, since two different objects could well share those attributes but differ in other respects. It would be like trying to define a real number uniquely by a finite number of the digits in its decimal expansion. Leibniz argued that, once one starts on the true identification of an actual thing, one must always end by giving a description of the entire universe. His bold conclusion was that, in reality, actual things are simply descriptions of the universe from different perspectives, like all the different views of a city.

I am not going to attempt to explain how Leibniz, starting from such an idea, arrived at his full theory of monads—his *Monadology*.[12] That would take a book. Instead, I will simply try to summarize the key ideas as best I can. This is how I understand his scheme.

Leibniz held that the entire world consists of nothing but distinct individuals, and that the sole essence of these individuals is to have perceptions (not all of which they are distinctly aware of). This position is superficially similar to Berkeley's idealism, according to which nothing exists except perceiving souls and ideas—perceptions—that God causes to appear to them.[13] But there the similarity ends. The most radical element in the *Monadology*, postulated rather than explained or made directly plausible, is the claim that the perceptions of any one monad—its defining attributes—are nothing more and nothing less than the *relations* it bears to all the other monads.

The monads exist by virtue of self-mirroring of each other; they all define each other. A monadological world is a perfectly bootstrapped world. It tugs itself into existence out of the mire of nothingness somewhat after the manner that Baron von Münchhausen got himself out of the bog.

Now how on earth could one begin to give substance to such a scheme? And why would one want to try? I would give three main justifications. First, the view that the world is relational is deeply persuasive and has been given strong support by the successes of general relativity and quantum mechanics. Thus, any model that develops relational ideas in a radical way is likely to have some value. Second, such a model must, if it is to have any interest, have a nontrivial structure. Leibniz gives us a valuable hint for how structure can be generated as a first principle. I shall come to this in the next section, but the introduction explained why such a principle may well be needed by modern physics. Third, there is simply the intrinsic interest of the attempt. Leibniz was, after all, one of the greatest and most original thinkers of all time. The *Monadology* is a marvelous dream, far more inspiring than Cartesian materialism. Can we show that the dream is reality?

3. Maximal Variety

Leibniz is widely held to have argued that we live in the best of all possible worlds. Voltaire made great fun of this idea in *Candide*, depicting him as the ever-optimistic Pangloss. However, if one reads the *Monadology* carefully, one finds that the principle Leibniz took to be the one that brings the experienced world into existence (rather than some other possible world) is not so much a maximization of goodness, but is much more closely related to the principle of individuation that is the foundation of his philosophy. According to this principle, individuals are distinguished by variety. The very essence of being is variety. What one means by "good" is notoriously difficult to define. How can one maximize something one cannot define? In contrast, something that *can* be defined and maximized is variety. Moreover, it is clear to me that this is the deeper meaning of Leibniz's scheme, for in paragraphs 57 and 58 of the *Monadology* we read:

> And just as the same town, when looked at from different sides, appears quite different and is, as it were, multiplied *in perspective*, so also it happens that because of the infinite number of simple substances [monads], it is as if there were as many different universes, which are however but different perspectives of a single universe in accordance with the different points of view of the monads. And this is the means of obtaining as much variety as possible, but with the greatest order possible; that is to say, it is the means of obtaining as much perfection as possible.

This passage prompted Lee Smolin and me, some years ago, to try to cast Leibniz's ideas into a concrete mathematical form. We published a few papers on the subject.[14] So far as we know, our models are the first such attempts of their kind. At the time, we harbored some hope that they might have direct application in physics. I am currently inclined to think that too optimistic and that the models have suggestive rather than prescriptive value. So, in the hope that one of my readers will take the original idea of maximal variety further, here is a description of the models. The first is more pure, the second more readily visualized.

First Model: A mathematical graph consists of *vertices* and *lines*. The vertices are going to model monads, the lines will represent the existence of relations between them. For convenience, we postulate that the number N of vertices is fixed. In the model, there is only one relation that can hold between two different vertices—either they are joined by a single line or they are not. More complicated models are possible but are not needed to get the concept across. Two examples are shown in Figure 1. It is important that the position of the vertices and the lengths of the lines joining them in the pictorial representation have no significance. All that counts is whether or not any two vertices are connected. It is assumed that each vertex is joined to at least one other vertex—the graph to which they belong is *connected*.

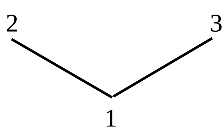

Figure 1a

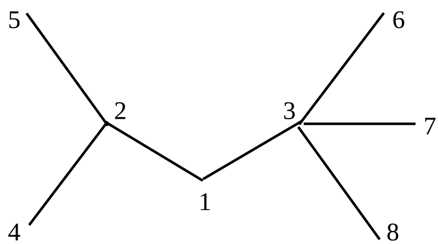

Figure 1b

In many applications, graphs represent salient relations within structures. Inessentials have been abstracted away. In Euler's famous first use of graphs, the vertices represented places in Königsberg and the lines bridges over rivers between them. Euler's only interest was whether all the places could be reached in a continuous walk that did not cross any bridge more than once. In such problems, the lines and vertices can be defined and identified by attributes that are not represented in the graph. Some vertices may have no connections to any other vertices, but one can still say they exist. They are identified by *extrinsic* denominations.

To model the *Monadology*, I shall insist that all denominations are *intrinsic*. I am not allowed to point and say: "That is vertex 1." Only graph-theoretical elements can be used. For example, in Figure 1a vertex 1 is unambiguously distinguished from the other two by saying that it is joined to *two* other vertices. Note than in such terms the two other vertices are indistinguishable. I shall call such a graph *non-Leibnizian*, since the two vertices seem to violate the principle of the identity of indiscernibles. Graphs in which all vertices are intrinsically distinguished are *Leibnizian*. For graphs with few vertices, it is difficult to find any that are Leibnizian. With increasing number *N* of vertices, the relative proportion of non-Leibnizian graphs among all those with *N* vertices falls rapidly.

The *r-step view* of any given vertex *v* in such a graph *G* is the subgraph of *G* obtained by starting at the given vertex and keeping all the vertices and lines that can be reached in not more than *r* steps from *v*. The 1-step view of vertex 1 in Figure 1b is the complete graph in Figure 1a. The 2-step view of vertex 1 in Figure 1b is already the complete graph, but for vertex 8 the complete graph is only recovered with the 4-step view.

The concept of *r*-step views can be used to distinguish vertices. Two vertices with the same *r*-step views are *r*-step indistinguishable, or *r-indifferent*. On the other hand, if the views are intrinsically different, they are *r-distinct*. The *indifference* of vertex *v* in graph G is the minimal value of *r* at which *v* becomes distinct from *every* other vertex in the graph. If *G* has *N* vertices and is Leibnizian, then *G* has *N* indifferences, one for each vertex. Call the sum *I* of the values of these *N* indifferences the *graph indifference*. If *G* is non-Leibnizian, let *I* be infinite.

Consider all graphs with *N* vertices. They are finite in number. Each has a graph indifference *I*. Since *I* is positive, some graphs, or perhaps only one, will have *I* smaller than all the other graphs of *N* vertices. For simplicity, suppose there is only one such graph. Call it the *maximal-variety graph*. Its vertices are more varied, more readily distinguished, than in any other graph of *N* vertices. Maximal variety selects—calls into being if you like—a world whose individuals "strive" to be as individualistic as possible. If, following Leibnizian epistemology, existence is identified as the possession of distinguishing attributes—the possession of positive variety—then a world in which this is well done is surely preferable to one in which distinction is botched. In this sense, a maximal-variety graph is the best of all possible worlds.

Second Model: Graphs are mathematically tractable but not readily visualized. The second model adds a bare minimum of spatial structure so that there is "something to see." Think of a wheel with *N* slots on its rim. Each slot must be filled with either a white ball or a black one. Suppose this done in some particular way. We are going to play essentially the same game but with a symmetry like the one inherent in the existence of matter and antimatter. (Given a particle with some charge and handedness, then its antiparticle has the opposite charge and handedness.) Two slots, *a* and *b*, have a relative indifference *I*(*a*, *b*) if they can be distinguished by the difference of their neighborhoods in a manner that does not say if neighboring balls are black or white or to the left or right. We can only say colors are the same *(S)* or different *(D)* and give the sequence. For example, the seven-member neighborhood with *a* at its center might be characterized by *SSDaDDS*, which we regard as the same as its reflection *SDDaDSS*. Using such sequences to compare the neighborhoods of *a* and *b*, we establish how many steps away from them one must go before the neighborhoods become different. The number of the step at which they become distinct is the relative indifference. The relative indifferences can be calculated for all pairs of the *N* particles. Summed, they give the total indifference *I* of the configuration. Once again, the configuration(s) with the lowest indifference have the maximal variety.

About ten years ago, I did some computer calculations to find such configurations with the Macintosh computer I then possessed. I was able to do exhaustive calculations up to $N = 27$, which took the computer about three days. Because the number of combinations that must be checked out grows exponentially with *N*, even with a modern supercomputer I doubt that calculations much beyond $N = 50$ would be feasible. However, I think the results I obtained then may already characterize the insights that can come from maximal variety. Let me first present them and then comment.

One can readily check that for $N < 7$ there are no Leibnizian configurations. They all contain at least two indistinguishable sites according to the above rules. For $N = 7$, there exists the solitary Leibnizian configuration:

(1) **xxoxooo**

which must be imagined bent into a ring with the first *x* (black) next to the last *o* (white). Since the model is color-symmetric, to say that a given site is black or white is purely nominal. The sequence *ooxoxxx* is counted as identical to *(1)*. But if we are to see anything, we must make a choice. I choose to call the color with fewer sites black.

The configuration *(1)* is the simplest solution of our optimization program for structure generation. It anticipates all the maximal-variety configurations that exist up to my limit of $N = 27$. With few exceptions, the maximal-variety configuration for a given *N* is not unique, though the number of such configurations is not large. For example, for $N = 14$ there are nine, for $N = 15$ three, for $N = 22$ four, and for $N = 27$ I found over twenty. I do not know if this indicates a qualitative change to significantly more maximal-variety configurations for each *N*. I found no evidence that the nature of the configurations themselves changes.

The following table gives all the maximal-variety configurations for $N = 21$ to $N = 25$, which happen to be conveniently few in number:

N	Configuration
21	**xxxooxoxoxoooxooooooo**
22	**xxoxoxoxxxxoooxooooooo**
	xxoxoooxooxoxoxooooooo
	xxxoxxxxooxoxoxooooooo
	xxoxoxoxxxoxxoxooooooo
23	**xxxooxooxoxoxoooxoooooo**
24	**xxxooxooxoxoxoooxooooooo**
25	**xxoxxoxoxoxxxxoooxooooooo**
	xxxoxxxxooxooxoxoxooooooo

Without exception, all the maximal-variety configurations possess certain very characteristic features. First, about one third of each configuration consists of a uniform run of sites of all the same color. As represented here, these are the zeros on the right. I shall call this uniform run *the space*. In all cases, the space is bounded at one end by a single site of the opposite color followed by another site of the same color as the space. At the other end of the space, there are always two or three sites of the opposite color. After that, the two types of site alternate, in a region that I shall call *the body*, in a manner that is impossible to predict without doing the calculations. However, the body is always asymmetric, having two different ends. That is predictable.

As a very simple model of the world and its evolution in time, one could suppose that the passage of time corresponds to the *creation of possibilities*, represented by an increase in the number N of slots that can be filled in such a model. Then the first instant of time corresponds to $N = 1$, the second to $N = 2$, and so forth. At each instant, the world is required to fall into a minimal-indifference configuration for that slot number—it is condemned to be creative forever and always to seek the maximal-variety configuration. The table shows us the evolution of such a world. We see a space and a body that evolve and grow in what seems to be a deterministic manner as far as the gross structure is concerned but in a probabilistic manner as regards the fine detail in the interior of the body.

Now, this is the kind of behavior that we observe in the actual world, in which the gross structure evolves in accordance with the deterministic laws of classical physics, while the microscopic structure obeys probabilistic quantum laws. At the time Lee Smolin and I developed such models, this outcome encouraged us to think that some form of theory based directly on the ideas of maximal variety could provide a realistic model of the universe. I still do not rule that out, but my thinking, influenced strongly by the belief that structure and variety hold the key to the laws of nature, has since developed in the somewhat different direction outlined in *The End of Time* and "Relativity without relativity" (notes 5 and 6).

There are several reasons why I have felt it worth returning to the idea of maximal variety. In the final section, I shall say something about its possible value for the light it casts on the kind of philosophical scheme Leibniz was trying to create. It might be a modest contribution to Leibnizian scholarship. To conclude this section, I want to say a few words about its possible value for certain basic issues in science and philosophy.

Let me start with holism versus reductionism and the related question of the whole and the part. It is the idea of an independently existing container space that makes the notion of atoms possible. When you look at the graphs in Figure 1, there is a temptation to think that the lines and vertices exist in themselves. This can be said of the actual lines and vertices on the paper, *but not of what they represent*. When you see a tree, that seeing is a primal fact. Just because you and the fact can be represented as a vertex and a line on paper does not give either you or the fact an independent existence. There's no paper in what you see. And you do not see yourself either. Properly understood, the graph is just one thing. Expanding the views from any one vertex, you always end up with the "universe" of the complete graph. There is a sense in which a vertex, identified with its fully extended view, is a part. But it is already the whole. The part is the whole, yet the whole is more than the part. Figure 1 does not look like much. But you comprehend it in a glance, and that comprehension is the perpetual miracle of simultaneous analysis and synthesis. You understand the connections in their totality but can also unravel them. Leibniz always said true unity is not achieved by mere aggregation like a heap of stones, but by a *principle of unity*. In its modest way, interpreted in pure graph-theoretical terms, a connected graph does express a principle of unity. It is a plurality within a unity, Leibniz's suggestive description of a monad. It is the principle of unity that makes the whole more than the part. If we can see the way to it, holism will trump reductionism.

When does information acquire semantic content? The well-known definition of information due to Shannon is extrinsic, not intrinsic.[15] Two agents agree to associate some meaning with a given set of symbols. The association is arbitrary. The same string of ones and zeros can represent a number or a declaration of war. Can such strings proclaim their own semantics? I believe they can, at least to some extent, if they possess an extremal property. The maximal-variety strings in the table do say what they are. They encode the law that brings them into being. In computer terminology, they are at once the algorithm, its outcome, and its meaning.

Somewhat related to this is the issue of defining order, disorder and complexity. Specialists give much thought to this. I am not going to claim that variety provides any definitive answers, but it does represent a specific and quantifiable measure of order. It may help us to understand the different kinds of order that are possible, for example in a crystal or in a living cell. Both are highly ordered but in very different ways. Random order is of a different kind and not like either. It is clear that a maximally varied configuration has an order more like that of a living cell than that of a crystal or random structure. In "Extremal variety as the foundation of a cosmological quantum theory" (note 14), these thoughts are developed a bit further.

To conclude: Leibniz's ideas can help us to comprehend the ontology of a relational and holistic universe, and perhaps even to find its meaning.

4. Leibnizian Philosophy Interpreted though Maximal Variety

Although maximal variety was developed mainly with the (long-term) aim of creating new physical theories, it may have interest in its own right as a mathematical model of the *Monadology* that sheds new light on some of Leibniz's claims. There are, for a start, two intriguing aspects of the model.

First, if this model is ever transformed into some kind of fundamental description of the universe, physics will come to resemble biology: all of the entities in a maximal-variety configuration are created in a kind of ecological balance between competing individuals. Each is trying to be as individualistic as possible, but in a curious way this selfish behavior is necessary if anything is to exist at all (for to exist is to become differentiated and hence to emerge from the mist of nothingness). By making ourselves differentiated, we cannot help but make other beings differentiated at the same time. The lion and the gazelle make each other. Surely Leibniz would like this mathematical example of how seeming evil is needed to make even the best of all possible worlds. Long live Pangloss!

The second aspect warrants a lengthier discussion. Consciousness in a material world is so baffling that idealism has always seemed more cogent than materialism. But hitherto nothing significant in the way of mathematical support to rival the triumphs of physics based on the hypothesis of an external world has been forthcoming. It is all very well for Bishop Berkeley to say that God implants ideas—perceptions—in our souls and that there is nothing more to it than that. But then why does God go to the trouble of ensuring that Einstein's general relativity correctly predicts the observed motion of the moon to millimeters? What weakens Berkeley's thesis is the incredible success of mathematicians and physicists in finding mathematical laws that presuppose an external world independent of consciousness. It is not good enough to say that God in his inscrutable wisdom has grounds to give us the impression that a world does exist out there. Scientists are not going to give up on the illumination that laws provide. To make idealism plausible, one needs laws that act directly and transparently on the raw stuff of consciousness: perceptions. Only then will the reductionist's atoms appear redundant. I want to suggest that Leibnizian principles might just enable the construction of a model of the world based directly on sense perceptions that does not lapse into solipsism or invoke a Berkeleian God who simply pops those perceptions into our souls. What I am going to propose now is, at the best, merely a demonstration of inherent possibility.

Suppose that a maximal-variety graph encodes the state of the world at a given instant. Take each view of the graph centered on a given vertex to represent the totality of the instantaneous perceptions of a sentient being—a monad. Each vertex "generates" a different view, which is simultaneously a different monad. For a given vertex, the lines and remaining vertices of the graph stand for two things at once—the relations of that monad to the other monads at that instant and the perceptions of that monad at that instant. According to Leibniz, the two are one and the same thing. The bare mathematical structure can be given concrete meaning by saying that a line from vertex i to a vertex j that has no other connections means that vertex i has some definite experience, say being aware of the color white. If j is connected to one other vertex, that could mean i experiences the color blue. For each type of vertex to which connection is made, there could correspond a definite sensation. Given such a lexicon—the translation from the bare elements of the graph to actual experience—we could read off the experiences of each of the monads within the graph.

Note that although the property of being joined by a line is a reciprocal relation, so that if i has an awareness of j we must also assume that j has an awareness of i, what is actually experienced will, except in rare cases, be different. This is because the other connections from i and j are not the same, and, by hypothesis, it is these other connections that determine how each vertex is experienced. In addition, in a maximal-variety graph there is a premium on difference.

It is interesting to consider in this framework Leibniz's famous remark that monads have no windows through which attributes might enter or leave a monad (*Monadology*, Section 7). This is trivially true in the present model; for in the bare graph-theoretical terms, the monad corresponding to a given vertex is nothing more that the listing of its connections to the other vertices. These connections are its attributes and it has no others. They could only be changed by considering a *different* (but similar) graph in which some of the connections have been changed. But, strictly, that is then a quite different world and consists of different monads. (Since we have assumed that the actually realized world is the one that exhibits the greatest possible variety, this modified world will possess less variety and hence fail to make it into existence—it will be one of Leibniz's 'possible worlds'.) Thus, each monad's attributes in the actually realized world are given once and for all. Each monad is, in fact, simply *the world as seen from its particular point of view*.

Seen in this light, I believe Leibniz was wrong to think that in a monadological world the mutual consistency of all the different monads—what he called the pre-established harmony—is a great miracle of God. In fact, it is a trivial consequence of the model. (The miracle is that *anything* is experienced.) In a graph, each vertex is willy-nilly a view of the whole from a given point of view. The graph defines all the views and enforces their mutual consistency. Moreover, as I have already said, it is inherent within the model that the whole consists of and defines its parts and that each part is simultaneously the whole.

In logical terms, it may be true that the monads have no windows. But in another sense, they are riddled with windows. What I as a particular monad experience is of necessity related to what the other monads experience. The experiences are not the same, but they are still related. Once I have achieved full self-awareness and understand in graph-theoretical terms why I have particular experiences, I will simultaneously know something about the experiences of the monad centered on the vertex responsible for my experiencing yellow. I can *peep* into the experiences of my fellow monads. Because of the way in which experiences are generated, we are all continually sharing experiences, though there is never identity of experiences.

In fact, the entire world is resolved into *pure shared experience*. This is an appropriate place to stop. If my conjecture is correct, this idea must resonate within you.[16]

This model is, of course, primitive, but it is always worth looking for different ways of conceiving the world. Let me leave the attempt at justification at that. However, I would like to make two comments about how my thinking has developed in the thirteen years since this model was first developed.

First, I have made no further attempt to develop mathematical realizations of idealism—not because I believe the venture is totally hopeless or worthless but because other goals, above all quantum gravity and advance in our understanding of time, seem to me more attainable. In fact, it was in the summer of 1991, while reading the proofs of my article "On the origin of structure in the universe" in which I first presented this model, that I suddenly had the notion of a time capsule, which is now my preferred idea for overcoming the problem of time in quantum gravity, as explained in *The End of Time.* I cannot possibly go into details, but the key point is that a time capsule is a static, highly ordered structure that contains what we interpret as records of a past that, strictly speaking, does not exist at all. If you have read my book, I am sure you will see how my earlier Leibnizian thinking helped me along the way to the idea.

Second, at the time that Lee Smolin and I developed these ideas, one of our aims was to try to construct a so-called 'hidden-variables' explanation of quantum phenomena. We wanted to explore the possibility that outcomes of quantum experiments that, in the laboratory, appear random but governed by probabilities are in fact uniquely determined by the overall properties of the universe. This is still a logical possibility, and Lee continues to take a lively interest in it. However, at the same time as I was working on the idea of maximal variety, I was also interacting with David Deutsch, who is one of the leading advocates of the many-worlds interpretation of quantum mechanics.[17] (He also contributed to this paper by proposing the precise definition of indifference in pure graph-theoretical terms.) Through David, I became convinced that the many-worlds interpretation needs to be taken seriously, and, in a somewhat modified form, it now plays a central role, along with Leibnizian ideas, in my current theory of time. φ

Notes

[1] C. Darwin, *The Origin of Species by Natural Selection* (1859).

[2] I. Prigogine, *From Being to Becoming* (San Francisco: W. H. Freeman, 1980).

[3] A. Albrecht, "Cosmic inflation and the arrow of time," in *Science and Ultimate Reality: From Quantum to Cosmos*, eds. J. D. Barrow, P. C. W. Davies, and C. L. Harper (Cambridge University Press, 2003).

[4] R. Penrose, *The Emperor's New Mind* (New York: Oxford University Press, 1989).

[5] J. Barbour, *The End of Time* (New York: Oxford University Press, 2000).

[6] J. Barbour, B. Foster, N. Ó Murchadha, "Relativity without relativity," in *Classical Quantum Gravity* **19**, 3217 (2002) <http://arXiv.org/abs/gr-qc/0012089>;
J. Barbour, "Scale-invariant gravity: particle dynamics," <http://arXiv.org/abs/gr-qc/0211021>;
E. Anderson, J. Barbour, B. Foster, N. Ó Murchadha, "Scale-invariant gravity: geometrodynamics," <http//arXiv.org/abs/gr-qc/0122022>

[7] G. Belot and J. Earman, "Pre-Socratic quantum gravity," in *Physics Meets Philosophy at the Planck Scale*, eds. C. Callender and N. Huggett (Cambridge: Cambridge University Press, 2001), 228.

[8] *The Leibniz—Clarke Correspondence*, ed. H. G. Alexander (New York: Barnes & Noble, 1956).

[9] J. Barbour, "Relational concepts of space and time," in the *British Journal of Philosophy of Science* **33**, 251 (1982).

[10] R. Descartes, *The Principles of Philosophy* (1644).

[11] See especially the Correspondence with Arnauld reproduced in *Philosophical Papers and Letters*, eds. L. L. Leroy, D.Reidel, Dordrecht (1969) and *Leibniz: Philosophical Writings*, eds. G. H. R. Parkinson and J. M. Dent (1973).

[12] The *Monadology* is included in both books (note 11).

[13] G. Berkeley, *Treatise Concerning the Principles of Human Knowledge* (1712).
[14] L. Smolin, "Space and time in the quantum universe," in *Conceptual Problems in Quantum Gravity. Proceedings of the 1988 Osgood Hill Conference*, eds. A. Ashtekhar and J. Stachel, *Einstein Studies*, Vol. 2 (Boston: Birkhäuser, 1991);
J. Barbour and L. Smolin, "Extremal variety as the foundation of a cosmological quantum theory," <http://arXiv.org/abs/hep-th/9203041>;
J. Barbour, "On the origin of structure in the universe," in *Philosophy, Mathematics and Modern Physics*, eds. E. Rudolph and I.-O. Stamatescu (Berlin: Springer-Verlag, 1994).
[15] C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication* (Urbana: University of Illinois Press, 1949).
[16] This article is based to a large degree on J. Barbour, "On the origin of structure in the universe" (note 14). I have left the final paragraphs almost unchanged since they seem to me to make a valid point. They still make me think, and I hope they have the same effect on you.
[17] D. Deutsch, *The Fabric of Reality* (London: Penguin Press, 1997).