

## Chapter 2

### The Freedom of the World

#### I. Fate and the Astronomers

Centuries before the scientific revolution, people knew that there were some processes in the physical world that were predictable, such as the motion of the planets, and some others that were unpredictable, such as lightning strikes. Today, many centuries later, our best scientific understanding is that this is, in fact, the way things are; but we have taken a very long and circuitous path to come back to this starting point, and we have (hopefully) learned much about the world along the way.

It must have been obvious to all the ancient peoples that there were forces and powers, far exceeding our own, at work in the world, and that these powers acted often in mysterious and seemingly arbitrary ways. Atmospheric phenomena, both spectacular and unpredictable, must have appeared as the natural seat of some of these invisible powers, and may even have invited their eventual personalization. The planets and stars, on the other hand, exhibited a much more subdued and regular behavior, but they were clearly citizens of the same realm as the sun and moon, whose influence and importance in human affairs were unquestionable, so it must have seemed natural to attribute to them, too, some kind of (necessarily more subtle) powers. Moreover, even though their motion through the skies would eventually become amenable to detailed prediction, the actual reason for that (sometimes very complicated) motion must have been an utter mystery to everybody.

The importance of being able to predict the trajectory of the sun across the sky, the solstices and equinoxes, was obviously already realized in prehistoric times, and the influence of the moon on the tides must have soon become apparent to all the peoples that lived near the sea; it is, thus, only natural that they should try to squeeze some more predictive power out of the heavens by studying carefully the motion of the planets, “just in case” they, too, happened to exert some unexpected influence on the world below. Astrology (which appears to have developed in every culture and even survived into our modern “scientific age”) can in this way be regarded as a sort of totally unwarranted generalization of a few sound astronomic and physical principles. It is, in fact, not uncommon for scientists to make the bold assumption that an explanatory principle that they have discovered to work well in a restricted setting actually must apply to the whole world; we shall see other examples of this before very long.

In any case, there is no question that human beings have always wanted to be able to predict the future as accurately as possible, although most of the time this has been done with the implicit understanding that, once in possession of the prediction, one could do something about it: for instance, a farmer might want to know when to sow, or a sailor when to sail. Yet, next to this rather sensible and, as it were, *limited* belief in the ultimate predictability of the world, one finds also what may be called the deterministic or fatalistic viewpoint, which is, in essence, the belief that our choices do not matter, they do not make any difference: the future is already written—

whether on the stars or elsewhere—and nothing we may do can change it.

It is probably fair to say that there is a bit of a fatalistic streak in every human being; certainly some form of fatalism has reappeared, over and over again, in every human culture. I think one possible reason for this is its dramatic potential: fatalism can provide some pretty good yarns to a good writer. Audiences have been enjoying the plight of the tragic hero who desperately tries his best to keep a prophecy from becoming true, only to inadvertently bring it to pass in the end, at least since the time of *Oedipus Rex*. It is partly the intellectual challenge, almost as in a mystery story (“how is the writer going to pull it off? How is the Great Birnam Wood going to walk to Dunsinane?”), and partly something like a thrill of fear, the momentary suspension of disbelief that goes with a scary story: we *know* the world does not really work this way, but for a couple of hours we contemplate the possibility that it *might*, and feel afraid—and then we walk out of the theater, or put down the book, and feel relieved that we are back in the “sensible” world once more.

Except, of course, that some of us never quite leave the theater or put down the book: some of us, it seems, really *do* believe in predestination, fate, the nonexistence of free will—or whatever one wants to call it. Even more remarkable, to me at least, is that entire *working* societies—societies whose members make promises and enter and enforce contracts, for instance—have been organized around basically fatalistic philosophies. I can only attribute it to some sort of cognitive dissonance: the well-known ability of human beings to live in ways that do not really follow logically from what we claim to believe.

In both the Greek and Norse mythologies, Fate was personified as an entity, or group of entities (the Fates, or the Norns; typically female, for some obscure reason) that trumped even the gods. In Christianity, a strong belief in predestination arose in the Calvinist branch of Protestantism, as a result of a fairly literal reading of a text of St. Paul<sup>1</sup>, and of the consideration of a paradox that arises from the traditional belief in God's omniscience. The paradox goes more or less as follows: if God knows everything there is to know, he also knows the future, which means he always knows what I am going to do before I do it; therefore, I have no true free choice.

There is an (also traditional) resolution of the paradox which is probably due to St. Augustine, and which basically denies the “before I do it” part of the above statement. The idea is that God exists fundamentally outside of time (although, of course, according to Christian belief, he can also manifest himself “inside of time,” but his fundamental mode of existence is “timeless” or, as some might prefer to say, “atemporal”). From this perspective, God's knowledge of the future is like that of someone who looks “from above” at a vast surface on which everything, past, present and future is “simultaneously” present. So God knows what I am going to do because, from his atemporal perspective, I have, in some sense, done it already; in any case, he does not learn about it “before” I do it, because where he sits there is no such thing as time, and hence there is

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<sup>1</sup> Romans 8:29-30: “For those whom he foreknew he also predestined [...] And those whom he predestined he also called...”

no “before” or “after.”

This is pretty heavy stuff for the 4<sup>th</sup> century A.D., but it would probably be unwise to dismiss it out of hand as a possibility. We know now, as I pointed out in the previous chapter, that there is no such thing as absolute time; time is inextricably linked to space, and the conventional (relativistic) notion of space-time should probably not survive beyond the Planck length, the unmeasurably small scale at which a quantum theory of gravity becomes necessary. For smaller distances than the Planck length, or earlier times than the Planck time in the Universe's history, there may not be such a thing as a space consisting of separate points or a time consisting of separate instants. Thus, the foundation of the physical world may very well be nonlocal (a fact towards which conventional quantum mechanics already points, rather strongly) and atemporal, and these might well be fundamental attributes of the divinity as well.

Still, while all this works fine for a hypothetical God that would never intervene in the ordinary flow of human history, for the Christian deity, which most definitely is supposed to manifest itself inside of time, the Augustinian solution does not lift all the difficulties. In order to preserve something like the freedom of choice of the God-that-acts-in-time, it seems that one would have to postulate the existence of a division, almost like a firewall, between God's atemporal essence and his temporal manifestation, so that the latter does not know what the former one has “learned” from his atemporal perspective. Strangely enough, there is what sounds like an echo of this very idea in a statement made by Jesus: “but of that day or that hour, no one knows, not even the angels in Heaven, nor the Son, but only the Father.”<sup>1</sup>

Personally, while I think there is probably something in the notion of what have been called, elsewhere, the atemporal/temporal “poles” of God, I find it too speculative for the kind of concept of God that I am trying to develop in the main part of this work<sup>2</sup>; and I find the original paradox to depend too much on a concept of God, and of God's omniscience, that is also too anthropomorphic for my taste. I am wary, as a matter of principle, anyway, of any reasonings based on “omni”-type concepts—omnipotence, omniscience, and the like—because I always suspect them of being ill-defined. It is like trying to calculate with “infinity” in mathematics, and pretty much for the same reason: what do you get when you subtract infinity from infinity? Why, you could get anything, of course<sup>3</sup>. It is an intrinsically ill-posed problem.

Notice, for instance, in the way I originally formulated the paradox, the assumption that God knows “everything there is to know.” But *is* the future really, in any meaningful sense, *there* to know? Where is the “there” in which the future “is”? In what sense can we say that the future even *exists*—other than from the very speculative “atemporal” perspective that I have tried to

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<sup>1</sup> Mark 13:32

<sup>2</sup> But I will return to the “block universe” picture introduced above in a (highly speculative!) Appendix.

<sup>3</sup> Here, for instance, is how to show that infinity minus infinity equals five: start with infinity and add five; naturally, the result is still infinity. Now take this infinity and subtract from it the first infinity: the result is five (or is it?).

describe above?

As it turns out, there is one sense in which one could argue that the future does “exist” now: if it is completely determined by the present, so that nothing “new” ever really happens, and things just inevitably unfold, as in the running of a simple computer program: the final result is already entirely contained in the initial data. This was the kind of universe in which materialistic determinists believed, for over two hundred years; and it all started with Newton and the motion of the planets, the old harbingers of fate to which we must return now.

## II. The Mechanical Universe

By the time (around 1677) that Isaac Newton came to tackle the problem of planetary motion, a number of important advances had taken place in our understanding of motion in general. Most importantly, the principle of inertia had been established: namely, that in the absence of external forces, motion on a straight line at constant speed can in principle continue “by itself” indefinitely. This made it apparent that what was needed was not a force to *push* the planets along on their orbits, but rather an inwards force (towards the sun, at last established as the center of the solar system) to *bend* their trajectories away from a straight line. At that point, gravity became a natural candidate for the job: we are all familiar with this force where we reside, on or near the surface of the earth; and why would it suddenly cut off anywhere? Why should it not continue outwards into space, perhaps as far as the moon, bending its otherwise straight “natural” path into a near-circle around the earth? And why couldn't the same mechanism explain the orbits of the planets around the sun? Newton had developed, practically single-handedly, a mathematical formalism that actually allowed him to calculate the trajectory followed by an object under the influence of a “central” force; assuming that the force varied as the inverse square of the distance between the centers of mass of the gravitating bodies (something that was suggested by a number of otherwise rather speculative “models” for the gravitational force), his calculations predicted that the orbits should be ellipses—precisely what had been established by the observations of Kepler<sup>1</sup> less than a century earlier.

Newton's results had the remarkable effect of explaining a mystery that had stood for centuries—the apparently arbitrary, and seemingly unassisted, motion of the planets through the sky—in terms of the most commonplace and ubiquitous of natural phenomena, something so (literally) down to earth that there had never been any question of inventing a “god of gravity.” When Sir Edmond Halley applied Newton's methods to the calculation of the motion of the comet that bears his name, and his prediction was verified upon the comet's return 76 years later, even this once-dreaded celestial traveler was utterly demystified, and shown to be subjected to the same natural laws as any stone thrown into the air, or a falling apple. It was perhaps the greatest early success of the new science of mechanics, which was to serve as a paradigm for all sciences for

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<sup>1</sup> Johannes Kepler (1571–1630). Strictly speaking, the actual astronomical observations were not made by Kepler himself, but by his late employer Tycho Brahe (1546–1601); but it was Kepler who recognized, after a painstaking, 16-year-long study of Brahe's data, that the planets' orbits were in fact ellipses.

centuries to come.

For Newton had not simply devised a new calculational method: he had actually provided a mathematical formulation for the very idea of what Aristotle had called “the efficient cause,” meaning anything that through its action directly causes something to happen. In the mathematical expression of Newton's celebrated second law of motion, “force equals mass times acceleration,”

$$F = ma$$

the quantity appearing on the left-hand side, the *force*  $F$ , is the cause of the *acceleration*  $a$  which appears on the right-hand side. The force uniquely and totally determines the numerical value of the effect, which is the acceleration, that is to say, the instantaneous change in the speed and/or direction of motion of the particle. Moreover, this acceleration determines the velocity at the next instant, and all the cumulative, infinitesimal (from one instant to the next) changes in velocity can be added (or “integrated,” as the technical term goes) to yield the position of the particle at any successive instant. In this way, the entire trajectory is *completely determined* by just the form of the force (typically taken to be a function,  $F(x)$ , of the particle's position), and by the so-called initial conditions, which are just the particle's initial position and velocity.

The result of Newton's formulation of mechanics is, therefore, a totally deterministic scheme of things, in which the initial state of a physical system (consisting, say, of any number of particles interacting with each other via arbitrary forces) entirely determines what it will be doing at any later point in time, forever after. It is in every respect like an idealized, perfect, frictionless clock: once you set it to begin with, you know exactly in what position the hands will be at any time afterwards. Nothing “new” ever happens: the motion of the hands unfolds mechanically and irrevocably from one second to the next. The future is perfectly predictable, as is, for that matter, the past: one just has to look at the current position of the hands to be able to tell exactly where they were, say, five hours ago. In this sense, the future is entirely written in the present. It is the vision of the world alluded to by T. S. Eliot in his poem *Burnt Norton* (1936):

Time present and time past  
Are both perhaps present in time future,  
And time future contained in time past.  
If all time is eternally present  
All time is unredeemable.

Eliot's last line hints at the darkest side of this vision: the possibility that the entire universe may just be such a clockwork mechanism, with no room left in it for freedom, or for the human soul. Such a state of affairs was in fact postulated, soon enough, by Laplace<sup>1</sup>, one of the most brilliant of the mathematicians who developed the science of mechanics following in Newton's footsteps:

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<sup>1</sup> Pierre Simon, marquis de Laplace (1749-1827)

An intelligence which at a given moment knew all the forces that animate nature, and the respective positions of the beings that compose it, could condense into a single formula the movement of the greatest bodies of the Universe and that of the least atom: for such an intelligence nothing could be uncertain, the past and future would be before its eyes.<sup>1</sup>

In modern terms, Laplace's vision of the universe is like a gigantic computer, mindlessly and endlessly carrying on its programming; in eighteenth-century terms it could be called a gigantic clockwork mechanism. One is somewhat struck (perhaps, admittedly, with the benefit of hindsight) by the astonishing sweep of the generalization: just because a particular mathematical model has worked well for describing some very special kinds of systems (planets interacting via simple force laws, moving through the frictionless vacuum of space), Laplace seems to believe that the same scheme must apply to everything else in the universe, including all the smallest parts of matter and the forces that bind them. As we shall see in the next section, this assumption was to prove spectacularly false, eventually; but the successes of mechanics at describing all kinds of earth-bound systems and laboratory experiments in the decades since Newton had been spectacular too, and no doubt went a long way towards explaining Laplace's assurance.

Clearly, the vision that threatened to remove the human soul entirely from the universe, also threatened to make the traditional concept of a personal God obsolete. In the mechanical universe, which seemed perfectly capable of running itself, God's only role appeared to be the setting up of the initial conditions, after which everything else was just the clock's gears ticking forever away. There was still, of course, the possibility of admiring God as the great designer of the whole thing—the master clockmaker, as it were—which seems to have been the way Newton felt; he also, incidentally, appears to have envisioned the possibility that God might have to intervene from time to time in the workings of the world, to adjust a little thing here or there, again much as a clockmaker would have to, occasionally, oil his device; but, by the time of Laplace, these considerations appear to have been set aside. In Laplace's view, the gears should be able to do fine by themselves, without any maintenance; and the infinitely distant God who, at some unimaginably remote time, had set the whole thing in motion, only to remove himself forever after from the scene, was utterly irrelevant. There is a story that when Laplace was introduced to Napoleon, the latter asked him (referring to his monumental work *Mécanique Céleste*), “M. Laplace, they tell me you have written this large book on the system of the universe, and have never even mentioned its Creator,” Laplace drew himself up and answered bluntly, “Je n'avais pas besoin de cette hypothèse-là.” (“I had no need of that hypothesis.”)

It goes without saying, of course, that none of the above beliefs and assumptions constituted in any way a logical proof of the nonexistence of God, or of his irrelevance; philosophers and theologians could still argue that nothing about the great Laplacian scheme, from the subsistence of matter to the continued validity of the force laws, was *necessary* (in the sense in which the

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<sup>1</sup> The quote is from the preface to *Essai philosophique sur les probabilités* (A Philosophical Essay on Probabilities, 1814). The hypothetical “intelligence” described in it has come to be known afterward as Laplace's Demon.

word was used in the previous chapter), and that, therefore, everything should be still considered to be kept into existence at every moment by the will of God; a will, moreover, that could just as well suspend the “laws of nature” for the purpose of working an occasional miracle as it had, presumably, originally brought them into being. And yet, the vision of the mechanical universe had a powerful compelling force. To many in those days, it strongly suggested a Universe that could really do without God.

Equally or more disturbing, on the human side, was, as I have indicated above, the hypothesis of total determinism and the absence of free will. It has been sometimes called “scientific determinism,” but in truth it was never very scientific: it was just the old fatalistic superstition in new clothes. As a purported statement of “truth,” it was intrinsically self-defeating: for, if Laplace is merely a sophisticated clockwork mechanism, what significance can anything that he could say have? Presumably he only says what he says because that is what he has been programmed to say, not because it bears any relationship to any kind of truth. Nor could I hope to “verify” anything he would tell me: I would merely end up believing him or not depending solely on whatever I was programmed to do. By denying the autonomy of the human spirit, the entire possibility of apprehending the truth—indeed, even of conceiving of the notion of truth—disappears, and with it the possibility of all scientific discovery or discourse.

And yet, such is the fascination that fatalism exerts on the human mind, that this particular system of belief (or unbelief, depending on your perspective) became relatively widespread among intellectuals, in the centuries following Laplace, and even among scientists who really should have known better. It is true that the practical successes of the materialistic, reductionistic hypothesis (namely, that every phenomenon in the physical universe could be explained by, or “reduced to,” the motion of particles of matter obeying a suitable form of Newton's equations) was so great throughout the nineteenth century, that the scientists who felt the need—not merely emotional, but also logical, as pointed out above—to postulate some degree of autonomy for the human mind were faced with a difficult proposition. The only escape from the hypothetical unbroken and fully deterministic chain of causation appeared to be to postulate the existence of some sort of “mind substance” that did enjoy some degree of autonomy from, and could, in turn, exert some sort of influence over, ordinary matter—whether only in a person's brain or perhaps, in a more speculative vein, over all matter at large, a hypothesis that may not have seemed entirely out of the question to some late twentieth-century scientists.

What turned out to be the case, however, was simply that Laplace was wrong.

### III. Quantum Mechanics and Unpredictability

Around 1925, a group of scientists loosely clustered around the Danish physicist Niels Bohr started figuring out the mathematical description of a new sort of mechanics—quantum mechanics—that would supersede the old Newtonian mechanics for the description of the

smallest (at the time) known particles of matter: electrons and atoms. As they worked their way through the many riddles posed by the indirect evidence that experimentalists had gathered about that, at the time, utterly invisible world, it began to dawn on them that the only possible theory for quantum phenomena would have to be not deterministic, but *probabilistic*; Newton's equation would have to be replaced by a similar equation, but for a different kind of entity: the thing being “determined” would now be, not a position or a velocity, but a *wavefunction*, or, very loosely speaking, a “wave of probability.”

Whereas the classical position and velocity variables gave one precisely what their names indicated—numerical values for the location of the particle, and the speed and direction of its motion—the quantum wavefunction merely gave the *probability* to find the particle at any one place or with any particular velocity. Two particles could have the same wavefunction, and yet, on observation, be found at different locations. And *no one could ever know why*.

It has been said that madness is to do the same thing over and over and expect a different result. This perhaps explains why quantum mechanics may have looked like madness to the thoroughly Newtonian physicists; for, in the quantum world, identical initial conditions, for identical systems, can and typically do lead to different measurement outcomes at later times.

Perhaps the simplest example, both theoretically and experimentally, is provided by a collection of atoms that have all been prepared in what is known as an “excited state”—a state in which they have a certain amount of “excess” energy. The atoms eventually get rid of this excess energy by emitting a photon (a “particle of light”) and “decaying” to their lowest possible energy state, also known as the ground state. The radioactive decay of nuclei is another example that follows a similar pattern. One speaks, in the latter case, of the nuclei's “half life” which is the time after which half of the initially excited nuclei have decayed to the ground state.

The above sentence contains, implicitly, the essence of quantum indeterminism. All the atoms, or nuclei, were prepared initially in the same state; all started out exactly identical; and yet, one half-life later, half of them have decayed and the other ones have not. Why did any one of the first group decay? We do not know. Can we tell at the beginning of the experiment which ones are going to have decayed by any given time? No, we can't. Another half-life later, half of the remaining atoms will have decayed. Again, we don't know which half, or why, or at what precise time any one of the excited atoms will decay.

In other words: we have no way to predict in any kind of detail what any of the *individual* atoms will do, but the evolution of the *ensemble* is far from totally random—in fact, as long as we have a sufficiently large number of atoms, the total number of excited atoms left after any given time is rather accurately predictable; we just don't know *which* atoms they are going to be. In this example, all the atoms start out with the same wavefunction, and the wavefunction clearly *conditions* the overall evolution, but it fails to *determine* it completely—at least, at the individual atom level.



One might take comfort in the idea that at least the evolution of the ensemble is predictable, but as we shall see in more detail in the next section, amplification of the quantum uncertainty surrounding individual decay events to the macroscopic level is by no means a rare occurrence. Consider, for instance, the photon emitted as the atom or nucleus decays. For a nucleus, this could be a highly energetic gamma ray. Not only is the time at which the photon is going to be emitted unpredictable, but also, to a large extent, the direction in which the photon takes off. So, in essence, *all* the radiation to which we are exposed in the ordinary course of our lives consists of individually unpredictable bursts. Suppose an individual gamma ray happens to strike an individual living being in precisely the right way to cause an (also unpredictable) mutation in its DNA, and this eventually becomes the progenitor of a new species. None of this was predictable in detail. Sure, one could expect, on average, a large incidence of mutations in a region with high natural radioactivity, but not precisely what shall occur, or when and where.

As pointed out above, in the early days of quantum mechanics some classically-trained physicists found this “quantum uncertainty” unacceptable, and tried to devise ways around it. Most vociferous in his opposition was Einstein—ironically, since he had played a decisive, indeed a foundational role, in the birth of the new physics. For Einstein, the fact that quantum mechanics could not tell you in what way an atom that decayed early and an atom that decayed late started out differently—since, by the Newtonian, deterministic logic, they *must* have started out differently—simply meant that the quantum mechanical description of “physical reality” was incomplete. And yet, attempts, over the past eighty years, to produce a more “complete,” deterministic theory to take the place of quantum mechanics—including Einstein's own efforts, that occupied most of the last twenty years of his life—have proved fruitless, while the intuition of Bohr and his colleagues has been vindicated time after time in extraordinary experiments on individual quantum systems, which few people back in 1925 would have imagined could have been realized one day.

These hypothetical, “more complete,” deterministic theories are often called “hidden-variable theories;” the idea being that the outcome of observations on individual quantum systems could *in principle* be predicted if the values of some (as yet unknown) variables, characteristic of the system under consideration, were known to the experimentalists. In other words, they are attempts to rewrite the laws that govern the quantum world in a form substantially identical to Newton's equations: given the (unknown) initial conditions, the outcomes of all subsequent observations would be wholly determined. Interestingly, not only are these hidden variables destined to remain forever hidden (since nobody has any idea of what they are or how their values before the experiment could be ascertained through a measurement), but experimental evidence has been mounting steadily for several decades now against the very notion of such a deterministic structure underlying the world of quantum events.<sup>1</sup>

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<sup>1</sup> The possibility to test experimentally whether “hidden variables” exist, regardless of what they are, provided that they satisfy some reasonable assumptions, was pointed out by John S. Bell in 1964. Since then, experiments have pretty much ruled out all so-called “local” hidden-variable models, and, most recently, some “non-local” models as well.

What are we supposed to make of this, then? Are quantum events “effects without a cause”? This appears unthinkable, and yet our normal understanding of causation, like so many other things, is born of the macroscopic world, where averages are taken over unimaginably many “quantum fluctuations,” and, as a result, predictability—at least, over short time scales—always holds in the strong Newtonian sense. Perhaps the problem is with the very notion of what we understand to be a “cause.” In any case, the verdict of Nature appears to be that the Newtonian mathematical formulation of cause and effect is too restricted: it simply does not cover all the possibilities present in the physical world<sup>1</sup>.

One of these possibilities is the one exhibited by isolated quantum systems, of behaving in *intrinsically* unpredictable ways. Einstein, in an often-quoted expression of disgust, likened this to “God playing dice,” but I think this does not even begin to do justice to what is actually going on here. Quantum indeterminism is nothing other than an assertion of *the freedom of the world*—the freedom to build its own future, to experiment, to explore; to be tomorrow something that nobody could have anticipated today. It entails the recognition that the future is not written anywhere, that the future, in fact, *does not exist yet*, not even as a blueprint.

One may think of the “veil,” mentioned in the previous chapter, that appears to conceal what a quantum system is “really” doing, as a way for nature to protect this freedom, more or less like we want privacy when we are going to cast a vote. Indeed, if we try to be too curious, and find out “how the thing works”—if, for instance, we keep probing an excited atom, asking over and over “has it decayed yet?”—we run into the familiar problem that an observed quantum system behaves differently from an unobserved one. In fact, constant observation of the sort just described has the effect of *inhibiting* the decay, and making the atom stay in the excited state for a time much longer than it normally would.<sup>2</sup> Of course, just because the freedom of the system can be curtailed in this way it does not mean that it does not exist in the first place, if the system is left alone; if anything, the opposite is the case.

It may not be immediately obvious how (or even if) we have managed to make this “freedom of the world” our own; but it seems clear that we *must* have, because it represents a *resource*, present in the world of inanimate matter, that could potentially be very useful, in a number of

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<sup>1</sup> At least one aspect of this mathematical formulation that was already questioned even before the advent of quantum mechanics is the implicit assumption of the infinite divisibility of time. In particular, classical (and even relativistic) mechanics assumes that it is possible to draw an infinitely sharp distinction, at any arbitrary, mathematical-point-like instant, between “the past,” where the “causes” are entirely contained, and “the future,” which they (presumably) wholly determine. Philosophers like Henri Bergson (starting in his 1889 work *Essais sur les données immédiates de la conscience*, known in English as *Time and Free Will*) have argued that this mathematical abstraction does not capture the real nature of time—what Bergson calls “*la durée*,” “the duration.” Interestingly, in quantum mechanics the so-called “time-energy uncertainty relation” shows that such an infinitely sharp division of time, into a “before” and an “after” the action of a cause, is impossible, because it would require an infinite energy. Put differently, any quantum field representing a finite-energy “localized cause” cannot, in fact, have an absolutely sharp spatial or temporal boundary.

<sup>2</sup> This curious “watched pot never boils” effect goes by the slightly more technical name of the “quantum Zeno effect,” and it has indeed been confirmed experimentally.

ways, to living beings: and if so, provided that there is any path<sup>1</sup> to incorporate it into the design of elementary forms of life, natural selection *will* incorporate it, and (if it continues to prove useful) pass it on, and continuously improve on it. Hence, we may have started with a simple form of life with a rudimentary nervous system that exploited “quantum indeterminism” for some kind of advantage, such as the ability to act in an unpredictable way, or to explore its environment using a “random” search approach; and this “portal” to quantum indeterminism eventually became embedded in the more sophisticated brains that followed, even as layer upon layer of improvements were added, such as the ability to learn (and hence to alter the “probabilistic landscape” where the decision-making takes place). Finally (for now, anyway) with the advent of human beings, self-awareness and conscious thought appeared on the scene, and, in relatively short order, they proved that they could make use of this built-in “door to freedom,” to create and dream the future, on a scale never before seen on earth<sup>2</sup>.

#### IV. Chaos and Creation

A well known result in quantum mechanics, closely tied to its indeterministic nature, is the uncertainty principle. In its most familiar form, it states that one cannot prepare a state of a particle in which its position and velocity (or more precisely its momentum—the product of the mass times the velocity) are simultaneously known with arbitrary accuracy. If the uncertainty in the position is denoted by  $\Delta x$ , and the uncertainty in the momentum is denoted by  $\Delta p$ , the mathematical formulation of the principle is the inequality

$$\Delta x \Delta p \geq h/4\pi$$

where  $h$  is Planck’s constant.

What is interesting about this is that, as pointed out earlier, in Newtonian mechanics predicting the trajectory of a particle required knowing both its initial position and its velocity (or, equivalently, its momentum). If only one of the two is known, then the subsequent trajectory cannot be computed. If either one or both are known only with some uncertainty, the computed trajectory will reflect this uncertainty; but this is precisely the situation that must always be the case, according to the above equation: it is impossible for *both* the position uncertainty and the momentum uncertainty to be zero. It is almost as if quantum mechanics had been “designed” with the express purpose of making accurate Newtonian predictions impossible!

One might think that this would not be a very big problem, in practice, because Planck’s constant is so small that, by macroscopic standards,  $\Delta x$  and  $\Delta p$  could simultaneously be very small

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<sup>1</sup> See next section for suggestions!

<sup>2</sup> Many of the ideas presented in this Chapter may be found also (among other places) in Appendix B of Questions of Truth, by N. Beale and J. Polkinghorne, where, additionally, specific examples of brain processes are discussed (with references) in order to show that the human brain’s operation cannot be deterministic.

indeed; but there is a catch, which did not become apparent until several decades after quantum mechanics was first formulated. It turns out that the systems of particles considered by Newtonian mechanics, and their interactions, fall into two classes. One class consists of so-called integrable systems, and has the property that two trajectories that start from very similar initial conditions remain always very close. This is as if one had two perfect clocks and were to set one of them initially a minute behind the other one. After several days, it would still be exactly one minute behind, neither more nor less. For such systems, any uncertainty present in the initial condition does not grow with time.

The second class of systems, however—and by far the most numerous—exhibits what is called “extreme sensitivity to initial conditions”: trajectories that start out very close together diverge extremely fast—exponentially fast, in fact (the same way compound interest accrues). A simple example of this is provided by the everyday action of pouring a little cream into a cup of coffee: the cream spreads and swirls rapidly, and molecules that may have started very close together are very quickly pulled apart.

These systems are sometimes said to exhibit “deterministic chaos”: deterministic because, in principle, given the initial condition, the trajectory is calculable; but “chaos” because, in practice, every time you start with a minutely different initial condition you end up with something completely different. Clearly, if you feed the unavoidable quantum uncertainty in either the initial position, or the initial momentum, or both, into a such a “chaotic” system, the result will be *un-deterministic* chaos—a trajectory that, after a short while, becomes totally unpredictable.

We may be a bit more precise than that. Suppose the quantum uncertainty, as applied to, for instance, a molecule that is undergoing thermal motion and colliding with other molecules, is so large, and the system is so chaotic, that we cannot predict anything about the position of the molecule after a couple of collisions.<sup>1</sup> If at any time we observe the molecule, we can roughly predict its motion for the first two collisions, after which it could be pretty much anywhere; if we then observe it again after a time has passed, the information we gain can be used for a new short-time prediction, and so on. We find that there is a sort of “predictability horizon,” beyond which any observation gives us fresh, new information—as if we had never known anything about the molecule in the first place. The past is, for practical purposes, constantly being erased, and the information that is going to be available in the future is constantly being *created*, seemingly out of nowhere—or, perhaps we could say, “out of the quantum mist.”

Here is an example of what I mean. Suppose I multiply two numbers, like 1.036 and 1.984. The result is 2.05542. If instead I change the last digit (third decimal place) to, for instance, 1.039 and 1.987, the result becomes 2.06449, which differs from the first one already in the second decimal place. Suppose this corresponds to a physical situation where I cannot measure beyond

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<sup>1</sup> This is, in fact, about right. For instance, for an air molecule at room temperature, the momentum may have a value of the order of  $10^{-24}$  kg.m/s, and the molecule's size may be of the order of  $10^{-9}$  m. This means that one cannot simultaneously specify the momentum to better than, say, one percent, and the (center of mass) position to better than a fraction of the molecule's size, without violating the uncertainty principle.

the second decimal place, so the numbers to be multiplied are actually more like 1.03? and 1.98? (where the question mark stands for the “inaccessible” digits). Suppose I measure the quantity that is supposed to correspond to their product, and I get 2.05?. The question now is, where did the “5” in the second decimal place come from? It came *from the question marks*; it came from information that was not initially “there.”<sup>1</sup>

In classical Newtonian mechanics, the evolution of a system is determined by an algorithm, and by the initial conditions; the output of the calculation, at any later time, does not, strictly speaking, contain any new information, nothing that wasn’t contained in the initial conditions: the algorithm can always be run backwards to recover the initial conditions, so the information I have at any time is really the same, only “encoded,” as it were, in different form. It’s as if, at the beginning, I had the word “cat” and at the end I had the word “gato”: they both contain the same amount of information, I just need to know the algorithm to convert one into the other (in this case, of course, the “algorithm” is to look them up in a Spanish-English dictionary).

But when I start with quantum uncertainty, the digits of accuracy needed to compute the solution even to the same accuracy after a certain time simply do not exist, and the result, after that time, might as well have been pulled out, literally, from thin air. It is as if I started with the word “dog” and ended with the word “ventana.”

In short: the combination of quantum indeterminism and classical chaotic dynamics results in the constant *creation of new information* in the universe. New information, not contained in the initial state, not available in any form, until it eventually and actually *becomes* available

Instead of the creation of information, we can equivalently speak of the creation of new—that is to say, unpredictable—patterns. The example of a decaying system of excited atoms, introduced in the previous section, already can be used to demonstrate this. Suppose I arrange all the atoms in a nice grid, and prepare them all in the excited state. A half-life later, I’ll have, instead of a uniform distribution of excited atoms, a (random) pattern: about half will have decayed, and the others will still be in the excited state, with no particular rhyme or reason to their respective locations. A pattern has spontaneously arisen where there was none. If I think of an excited atom as, say, a “1”, and a ground state atom as a “0”, I could even “read” the pattern as a word in binary code: I could say that the (inanimate) world had spontaneously written a “word.”

Of course, the “word” in question would be meaningless, but the way of nature is that first it innovates, and then it tries to make sense of what it has done. Put differently, new, unpredictable patterns are constantly arising, and immediately being “tested” by their environment. Most fail the test and simply go away, but a few turn out to be sufficiently stable to grow and develop into something larger. A mutation in a living being may turn out to be beneficial, and be passed on; a fluctuation in a physical system may become stabilized and serve as a seed for something to

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<sup>1</sup> Note that assuming that the position and momentum of the particle really have enough (unknown) decimals to determine, in principle, the trajectory of the particle to the desired accuracy (through the use of classical mechanics or of any other algorithm), amounts to postulating a “hidden variable” theory.

grow around it, whether a crystal, a cloud, or a lightning discharge.

The processes of diffusion and mixing mentioned earlier—the cream dissolving in the coffee—are archetypal chaotic systems. Together with quantum uncertainty, they will naturally lead to unpredictable density fluctuations in liquids and gases. These will cause local changes in concentrations of chemicals that living beings may rely on for a variety of purposes, from development to motion. The end result will be, at a minimum, a touch of unpredictability in all living things, both in what they do and in what they look like.

At the same time, this randomness does not, of course, go unchecked. As a system grows beyond the quantum realm, the fluctuations tend to cancel out and its behavior becomes more deterministic; it then interacts with many larger, stable structures that, in turn, create predictable force fields, that tend to channel and regulate the larger system's (say, a living being, or a large physical phenomenon, like the weather) operation. Hence, our world shows, over both time and space, a balance of predictability and unpredictability that renders it certainly much more interesting than a clockwork mechanism, if somewhat less reliable.

In fact, it could be said that this balance, even on a “human” scale, is not very different from what is already encountered in the quantum world: namely, individual peculiarities are typically unpredictable, but average traits or patterns of behavior are largely predictable. The kinds of clouds one gets on a certain kind of day are typically what the weatherman forecast the day before, although their individual shapes, and even the precise time at which they show up, may well be entirely beyond the realm of prediction, even for Laplace's demon.<sup>1</sup> A maple leaf will always be clearly recognizable as a maple leaf, although no two leaves will ever be found that are identical in every detail. And a child will typically resemble his or her parents, even though no one could anticipate in what precise way. Even identical twins, as it turns out, have different fingerprints.

In short: through the combination of intrinsic indeterminism at the quantum level, microscopic dynamical processes that can amplify these quantum fluctuations, *and* a large number of very nearly deterministic processes on the macroscopic, “classical” scale, that impose a sort of constraint or boundary condition to the whole process, the physical world may be said to be endowed with a *creative power*: the ability to continually bring about new structures and patterns, both in the living and the inanimate realms; to keep the future both somewhat predictable and open to change; and to continually, yet gradually, “renew the face of the earth.”

Note that *both* the deterministic and the indeterministic component are essential to the process of creation as described here. Unbounded chaos would not create any stable, lasting structure or organism: merely patterns that would dissolve as soon as they appeared. But strict deterministic

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<sup>1</sup> The weather is, in fact, the most notorious of all classically chaotic systems, and it was in the context of weather prediction that the concept of “deterministic chaos,” or “extreme sensitivity to initial conditions,” was first received broad attention. An often-encountered way to express this is the statement that “the flap of a butterfly's wings in Brazil may set off a tornado in Texas” (the so-called butterfly effect).

laws would never allow for anything genuinely new to emerge, either. For the world to be what it is, for us to be what we are, the balance of chaos and order that we observe is absolutely necessary.

To see this in yet another way, consider the way humans (and possibly other animals) often make decisions, by visualizing the consequences of the different choices available to them. Such a visualization is only possible if the world is orderly enough for actions to have mostly predictable consequences; and it is only meaningful if the world is indeterministic enough to allow for an actual choice, otherwise the visualization exercise would serve no purpose. Of course, the proper way to look at this is that we have evolved to make decisions the way we do, *precisely* because the balance of predictability and indeterminism in the world is what it is.

There is a regrettable tendency among some people of Christian background—perhaps going back, at least in the English-speaking world, to Milton’s *Paradise Lost*—to identify God with order and the devil with chaos, and to sometimes even go a step further and, in effect, side with “the devil,” thus conceived as the true embodiment of creative freedom.<sup>1</sup> This identification of chaos or “unconstrained freedom” with creation is wrong from a purely factual perspective, as indicated above: for anything truly lasting to ever be created, some amount of “order” is just as important as a measure of unpredictability, or “chaos.” But, also, from the theological or philosophical perspective that I am attempting to develop here, the whole notion of putting God and the devil side by side (or face to face) is quite misguided, no matter how one may try to “fix the picture” by immediately declaring that God is infinitely greater, or whatever: one has already committed the “Far Side cartoon fallacy” of imagining God as a being *in* the universe, a being *among* other beings.

This will simply not do. Whenever two figures—“God” and the devil, in this case—stand side by side, obviously neither one can claim to be the Absolute. There is clearly something greater, more *ultimate* (if one can actually say that!) than either one—and that is simply *the background against which they both stand*.

The Ultimate Reality that we call God, then, is neither chaos nor order: it is the reality *behind both* chaos and order, that causes both to exist and determines their balance. As such, it is the source of Creation, because it is *the source of the creative power manifest in the physical universe*.

## V. At Home in the World

Arguably the oldest and most traditional role for God is that of Creator of the world. The purpose of this chapter has been to explore what this can mean, beyond the statement made

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<sup>1</sup> In fact, the idea of looking on (humankind’s) creative powers as somehow “demonic” in origin is probably much older than Christianity, but that’s neither here nor there. See also Goethe’s *Faust*.

already in the previous chapter that God is “existence itself,” and hence the source or foundation of all that exists. To this end, I have attempted to look specifically at the way in which, here and now, but also, presumably, in the distant past, in the physical world that we inhabit, new contingent beings actually come into existence (first, of course, having had to settle the determinist’s question of whether anything really *new* ever comes into existence!).

The answer is that, basically, this process that we might call creation-in-time (as opposed to Creation understood as above, that is, providing the foundation for all there is, and ensuring its continued existence) takes place via *evolution*, with the term understood in a very general sense: namely, to denote the constant arising of new structures and patterns, that are tested by their environments, and, if successful, become stable and grow (and, in the case of living beings, self-replicate).

There is a strong prejudice among some religious people against the very notion of evolution, probably because of its apparent strong dependence on randomness or “chance.” Of course, statements like the following, famous one, by the distinguished French biologist Jacques Monod<sup>1</sup>, do not exactly help:

L’ancienne alliance est rompue ; l’homme sait enfin qu’il est seul dans l’immensité indifférente de l’Univers, d’où il a émergé par hasard.

(“The old covenant is broken: Man knows at last that he is alone in the uncaring immensity of the Universe, from which he has arisen by chance.”)

At least two comments can be offered in this regard, however:

- First, when we say “chance” we simply mean “not determinism” of the blind, Newton-Laplace type. That this may appear to us as equally blind randomness is just a consequence of our mental make up, which seems largely incapable of conceiving a third alternative. The truth is that we simply do not understand what this thing we call “chance” *really* is.
- Secondly, what quantum mechanics does is to break one particular (hypothetical) chain of causation, by showing that pure “bottom-up” determinism (from atoms to humans, say) does not hold. It is, however, entirely conceivable that there may be other kinds of causes at work in the world, compatible with the laws of nature as we know them but taking advantage of them for specific purposes. These “top-down” causes certainly include what we call the human free will (about which a bit more will be said in the next chapter), and there is no reason a priori why the list should stop there.

But set aside for a moment these considerations; take the word “chance” to mean nothing more than pure, blind randomness, and grant Monod that that is, indeed, how we have all ultimately

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<sup>1</sup> Nobel-prize winner and author of *Le Hasard et la Nécessité* (Chance and Necessity, 1970), from which the quotation is taken. I must admit that I have never actually read this—once very influential—book, but I have reason to believe that some of the arguments against determinism that I have set forth here may be found in there as well.



come into being. Must it follow necessarily from this that we are worthless, that nobody wants us here, that we are unwelcome “in the uncaring immensity of the Universe”?

Of course not! To begin with, we have not, each of us, come into being somewhere out there in interstellar space, but right here on Earth, our species’ home planet for tens of thousands of years already. Evolution has had plenty of time, both before and after we became *Homo sapiens*, to fine-tune our bodies—whose basic plan goes back millions of years—to make sure that we are a good fit to our environment. We are definitely not “strangers in a strange land.” We *belong* here.

Everywhere in our bodies can be found reminders of millions of years of living on this planet. Our stomachs carry bacteria to help us digest the foods provided by the earth’s biosphere. Our eyes are optimized for maximum sensitivity at the peak spectral emission of the sun, our star; our skin will synthesize vitamins from the radiation of that same star, and tan to protect us against excessive sunlight. We breathe oxygen, the second most abundant element on our atmosphere, which is, itself, released by other living beings.

*We have grown up with the world. This is our home.* We can walk down a country road and find wild berries, and pick them and eat them, and they will be both delicious and nutritious—and the reason is that they evolved so as to be that way for some prehistoric creatures, to which we are, obviously, related. Ultimately, though, we are also related to the plant itself, and to the soil from which it grows, and to the rain that waters it, and even to the sun that powers it: we all sprung from the same primeval dust left over by the explosion of a local star, billions of years ago.

Contemporary biologists like to suggest evolutionary explanations for many of our “built-in,” instinctive responses, such as why we are afraid of snakes, or why we like the scent of the earth after the rain, or even why minor triads sound sad. Some of these sound to me more like modern myths than real, verifiable scientific explanations; but, to the extent that they help strengthen in us the awareness of our ties to the earth, and to the great river of life, I think they are good myths. In any case, it is not necessary to know, or to think we know, the reason why the world makes us feel a certain way: it is enough to know that there is almost certainly a reason, that probably goes back millions of years, that is inextricably linked with the great history of life on Earth; and that the particular feeling we experience is probably much the same that our distant ancestors felt when they first stood, ages ago, on the African plains.

Far from making us feel lonely or alienated, the contemporary understanding of the evolution of both living and nonliving things should, ultimately, reinforce in us the belief of St. Francis of Assisi: that all the things that surround us, all the things we have grown up with, the sun, the water, the birds and the flowers, are our sisters and brothers; and this cozy little corner of space is our ancestral home, the house that our Father—the mystery-shrouded Reality that endowed the

world with its creative freedom—caused to be built for us.<sup>1</sup>

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<sup>1</sup> It could be countered that, if it was all up to chance, nobody could have known that we would have ever arisen, but that misses the point: the house was built for *everybody* and anybody (see Matthew 6:26-30). Obviously, many planets will not support life, but on every planet that does, evolution will produce beings that are “at home” in their environment, whatever they (or their environment) might happen to be. (Please note, however, that with this I do not in the least intend to deny the reality of suffering in the world; indeed, that reality will be the subject of a whole separate chapter below.)