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Why the Future Cannot Be Totally Predicted

Scientific determinism vs. human moral responsibility

From the beginnings of the rise of modern science in the seventeenth century, the problem of determinism has been one of the central worries within western thought. If modern science were to eventually give us all the answers to all the possible questions, and explain exactly why everything happened the way it happened, wouldn't this put us in total control of the world, and turn us into the masters of the universe? And wouldn't this totally remove the need for God? Many of those who were the friends and defenders of modern science proclaimed that this was so, and looked forward with pleasure to being able to destroy the power of the ignorant, hypocritical priests and nuns, and pastors and rabbis, who had scolded and frightened them and made their lives so miserable during their childhoods. “Down with religion and up with science!” became their battle cry.

But a nagging doubt tended to creep into this atmosphere of congratulation. Wouldn't this also remove all human free will and moral responsibility? "I killed the eighteen-year-old convenience store clerk after robbing her of $13.53 from the cash register, because of my early childhood upbringing. You can't punish me because it wasn't my fault. It was my mother's fault, society's fault, the fault of the laws of nature." Scientific determinism seemed to take away all our power of self-determination at the same time that it held out the hope of us becoming the masters of the universe.

We can see the first statements of the idea of scientific determinism being expressed as early as the time of the philosopher Leibniz (1646-1716). What he called in his philosophical system the *principle of sufficient reason* basically required us to embrace a theory of total causal determinism. "Nothing takes place without a sufficient reason," he said. "Nothing occurs for which it would be impossible for someone who has enough knowledge of things to give a reason adequate to determine why the thing is as it is and not otherwise." And it seemed impossible to deny that this was the basic working principle of the modern scientific method.

If we note the sun and moon and planets moving across the background of the fixed stars, for example, we can ask why this happens the way it does. We can carry out careful research and try out hypotheses until finally we successfully discover *the reason why* this happens. This was of course exactly what was done by Sir Isaac Newton (1643-1727) during Leibniz's own lifetime, and the result was Newton's explication of the three laws of motion which lay at the heart of classical physics.

Leibniz vs. Kant

It was the philosopher Kant (1724-1804) who became the most important spokesman from that general period for those who were concerned about the other side of the issue. He saw Leibniz's philosophical position as the destruction of any notion of real moral responsibility. It was that — not God — which was the central problem in his eyes. In fact, Kant was not concerned at all about belief in God. In a footnote to one of his books, he stated that he sort of believed that there probably was, or might be, a God of some sort, but he added that he certainly did not believe that he could prove that. And other than that, Kant's Critical Philosophy was basically an unrelenting attack on traditional belief in God.

But Kant believed that he had at all costs to figure out a way of defeating the idea of total causal determinism and providing for some kind of human free will somewhere, even if only in certain limited kinds of situations, or human moral responsibility would be totally destroyed, and with that, the concept of humanity itself, and what the Boston Personalists would later on describe as the fundamental concept of human personality and personhood.

Scientific determinism and Laplace's Demon

It was not until the beginning of the next century that the French mathematician and physicist Pierre-Simon de Laplace gave in the introduction to his *Essai philosophique sur les probabilitéés* in 1814 what is still regarded as one of the simplest and clearest descriptions of the theory of scientific determinism:

> We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

I am going to take Laplace's formulation as my basic statement of the principle of total scientific determinism in the discussion which follows. This basic idea has been regarded as an article of faith by an enormous number of modern philosophers and thinkers ever since. What it stated was that a sufficiently intelligent and knowledgeable observer (sometimes referred to by modern philosophers as "Laplace's Demon") who knew all of the scientific laws which govern the world of nature, and all of the principles of mathematics and logic which underlay these laws, together with all the data, would be able *in principle* to completely predict the future course of the universe down to the last detail.

Now that little phrase "in principle" is an important one to notice. Because we do not in fact know all of the laws of nature, and we also do not in fact have all of the data explaining the location, energy, and so on, of every nuclear particle and bundle of energy in the universe.

But philosophers who argue that the universe is totally determined by the laws of science brush this aside, by agreeing that this is so, but then saying that this is irrelevant, because *in principle* it is so clear and obvious that we could predict the future with this kind of unfailing accuracy once we had obtained all these laws and data.

I remember when I won the *Prix de Rome* in 1978 for my work on ancient Roman history and was able to spend a delightful year at the American Academy in Rome, that there was a wonderful Italian phrase which I often ran into in going about Italy. Some American would be explaining to an Italian how the rules said that it was possible to do such-and-such in such-and-such a way, and the Italian would smile broadly and say, "*Si, si, in principio, ma* .... " "Yes, yes, in principle, BUT ...." and then explain how things were actually done, which was usually quite a bit differently!

So my answer to Laplace's Demon and his claims is to say, "*Signor Demonio, si si, in principio, ma* ...." It is a good theory, but reality does not work that way, for many fundamental mathematical, scientific, and philosophical reasons. In this chapter I want to begin exploring why total scientific determinism does not in fact work, and in particular does not work the way Laplace and his defenders have claimed, without falling into the traps that were laid in Kant's attempts to defeat the idea of determinism. Or in other words, I want to explain how we can defend human free will and moral responsibility without destroying the idea of God in the process.

Defending human free will against the clockwork universe

The philosopher Kant agreed with my basic claim here: he insisted that the idea of a universal causal determinism was an illusion, an artifact produced by the way that our minds attempted to create a phenomenal world — a statement which I believe is completely true. But in his *Critique of Pure Reason* (1787), he gave no real reasons for why this was so, other than the bald statement that it was impossible in practice to carry out all of the causal analysis to its conclusion.

A more important problem, however, was that the only situation in which Kant was able to argue for any kind of genuine human free will was when our minds rose up into the realm of the pure ideas, and there chose appropriate categorical moral imperatives by which to live our lives — general principles arrived at (and adhered to) without reference at all to any specific moral cases within the material world of space and time.

I want to begin showing in this chapter that there are in fact basic principles of logic and mathematics and science and information theory which make a total causal determinism impossible in terms of basic theory itself. We must go beyond Kant. It is not just that it is impossible at the practical level to work out a total solution for why all things happen exactly the way they happen, down to the finest details. It is impossible in terms of basic principles. And I want to show later on that human free will is much more extensive than Kant ever acknowledged, because that is equally important.

But most of all, I want to demonstrate by the end of this book that Charles Hartshorne and the process philosophers were basically right, in that human personality and the personhood of a real God, who knows us and loves us, and whose influence is felt in every aspect of our lives, is necessary for understanding how the enormous fruits of modern science can be best appropriated by removing the idea of an implacable universal determinism, and replacing it with a vision of a universe in which real creativity and real novelty can occur. What is the point of modern science, if it does not produce acts of genuine creativity and genius, and if it does not allow us to shape a world in which human beings will be able to obtain greater happiness, and in which love and kindness and true compassion can abound?

Or to put it another way, Laplace's Demon produces a deterministic universe in which we see human shapes moving mechanically like the figures on one of those old ornate clock towers found in Central Europe, where whenever the clock strikes the hour, a doll-figure shaped like a man with a hammer comes out of a little door in the front of the clock and circles around, hitting a bell to tell what hour it is, or performs other mechanical actions, and then returns (on its gears and cogs) back inside the clock through another little door. Or a cuckoo comes out a door above the dial of one of those marvelous clocks built in Germany in the Black Forest, and cuckoos however many times to indicate what hour it is, and then is pulled back inside the clock again by the clockwork mechanism. Laplace's Demon turns us into mechanical men and women and cuckoos who go through life cuckooing and hitting bells simply because that it is the way the gears and cogs make us move and cry out, with no ability to act in any way other than the ways the laws of nature compel us to move and cry out.

That is not only a grim view indeed of the nature of human life and the universe, it also flies in the face of what our own common sense tells us. Sometimes, even though everything in the underlying mechanism is trying to make me cry "Cuckoo," I decide to say something else instead. The history of real scientific progress, and real individual spiritual growth, is a history of brave and insightful individuals deciding that there is something which would be better — or at least more fun, or more creative and delightful — than shouting "Cuckoo" in the way that the mechanisms of the past were trying to get me to shout.

In the history of evolution, until we arrive at true *Homo sapiens*, we discover that our ancestors (even our close cousins the Neanderthals) had great problems in doing things in any way different from the ways they had been programmed to do them. Neanderthals kept on chipping out the same ax heads in the same ways for thousands of years. They put no artistic decorations on any of the things which they constructed. But then the first true *Homo sapiens* appeared, and instantly we have this fierce joy in figuring out ways to chip an ax head in a little bit different way — maybe better, but at least different from the ways our grandparents chipped them — and sheer delight in discovering the bow and arrow, and how to make pottery, and weave cloth, and above all, in finding new ways to decorate our homes and the objects we used with artistic motifs which had no necessary practical utility, but made things beautiful and gave us joy and pleasure. Novelty, creativity, discovery, and free will are of the very essence of true humanity. If we successfully argued ourselves into believing that we were no more than clockwork figures moving mechanically, the best we would be able to accomplish would be to send ourselves back to the cave again, living like *Homo habilis* and *Homo erectus* and *Homo neanderthalensis*, and the other species of ape people who lived before modern human beings came along.

The twentieth century

I should also say, before going any further in this chapter, that it is the discoveries made in physics, mathematics, and logic which were made during the course of the twentieth century — during my own lifetime in fact, or just before I was born — which force us to totally revise the picture of implacable causal determinism portrayed in the notion of Laplace's Demon. I have had the privilege of living in very exciting times, to say the least, an era which has changed the fundamental presuppositions of human thought in a massive way seen only once before in human history, during the period of the Classical Greeks.

Or to put it another way, the Greeks showed us that it was not helpful to recite ancient near eastern myths and say that gods caused earthquakes, epilepsy, and the other phenomena of nature. And likewise, the great scientists and thinkers of the twentieth century, working in Europe and North America — the new ”classical period” if we chose to so designate it — showed why and how Laplace's Demon was not helpful either, and liberated us to achieve a new vision of the infinite worth of the human personality, and a new vision of the divine world, centering on a loving personal God, who can and will save our souls and lives when we are hellbent on the road to destruction.

The ancient Greeks, in their tragic drama, showed with beautiful clarity how we place ourselves on the road to tragic doom by our own wills and decisions and obstinate actions, but they devised no ways to stop these tragic heroes and heroines once they were embarked upon this destructive road. In the twentieth century however we discovered ways of halting that plunge to tragic doom. Alcoholics Anonymous and the twelve step movement which followed it was, in my view, the twentieth-century group *par excellence* which understood the genius of the new view of the universe and of spirituality which was emerging, because the Big Book of Alcoholics Anonymous (as well as the writings of the other early A.A. authors like Richmond Walker, Ralph Pfau, Ed Webster, and so on) were able to separate spirituality so decisively from outmoded pre-twentieth century modes of thought without losing any of the ancient power of divine grace and the experience of the holy, and because they demonstrated in literally millions of changed lives that they could reverse the horrifying descent into tragic doom.

And these new ways of looking at ourselves and the universe will literally save our planet, and the human race itself, from destruction at the hands of the some of the other developments of the new science which were also unleashed. We will learn this, or we will die, from drugs and nuclear bombs and global climactic changes and the creation of totalitarian dictatorships — both secular dictatorships based on crazed pseudo-scientific notions, and dictatorships based on blindly authoritarian religious principles grounded in a world long vanished, which have no solutions to our modern problems — for these destructive forces too were part of what the twentieth century bequeathed us.

"Choose this day whom you will serve," as Joshua once said to the Israelites (Joshua 24:15). Will we attempt to solve the problems of the present by trying to live in the past? The consequences will be incredibly destructive if we try to go back to the nineteenth century and the grandiose proclamations of some of the would-be scientific philosophers of that age of secular atheism. But the consequences will be equally destructive if we try to go back to an even earlier century, and join hands with those religious fundamentalists who want us to live by the authoritarian moral codes of the dark ages. Will we continue to try to live in the past, or will we try to create a decent future for those who today are hurting and helpless, and those who are going to be hurt in generations to come if we obstinately and fearfully and blindly continue in the old ways?

The two body problem

But let us move on to a more careful philosophical analysis of the problem of determinism, beginning our attack on Laplace's vision of a totally deterministic universe by looking at something extremely simple and obvious, which for some reason seems to have been completely overlooked by most people talking about this issue.

Modern mathematical physics is based upon the mathematical techniques devised by thinkers like Descartes (and the Cartesian coordinate system which he devised in 1637) and Sir Isaac Newton (who published his *Philosophiae Naturalis Principia Mathematica* in 1687 and gave us the foundations of classical physics).

Newton showed that he could calculate the motion of a planet (like the planet Mars) around the sun by placing the sun at the center of his coordinate system, and then working out equations to describe how the force of the sun's gravity compelled the planet to move around it in an elliptical orbit, speeding up in the part of its orbit which was closest to the sun (which was at one focus of the ellipse) and slowing down as it plunged into the further reaches of its orbit. This is the classic two body problem.

The foundations of modern quantum physics were laid by the Danish physicist Niels Bohr (1885-1962) who published his work on what is called the Bohr model of the hydrogen atom in 1913. This too was a version of the classic two body problem. Bohr placed the positively charged proton which formed the nucleus of the hydrogen atom at the center of his mathematical coordinate system, and then calculated the position of the negatively charged electron which moved in an orbit about this center. Just as the sun's gravitational pull tended to pull the planet Mars towards it in Newton's model of the solar system, so the electrical attraction between positive and negative charges tended to pull the electron towards the proton.

In this case however, Bohr discovered that the electron could only occupy certain orbits at narrowly specified energy levels. They were "quantized." If one bombarded the hydrogen atom with energy, and the electron absorbed some of this energy, it could not move smoothly up to a higher energy level, but had to move up stepwise, jumping from one specific quantum level to the next. Bohr's calculation of these quantum levels matched up with the spectrum of hydrogen as observed, not only in the laboratory, but also in the sun and other stars. When the electron in a hydrogen atom jumped down to a lower quantum level, it emitted electromagnetic radiation (some of it at the level of visible light) at the precise energy levels (wavelengths) which separated the quantum levels of the possible orbits.

The insolubility of the three body problem

What is not realized by most people who are not mathematical physicists, is that although the two body problem is something that can be handled — indeed is at the heart of many of the formative discoveries in physics in the modern period — the three body problem is *not* solvable, except in certain odd kinds of circumstances.[1] So if we took three molecules of oxygen, for example, and placed them in a cylinder and then tried to calculate their simultaneous interactions, it would be impossible, because there is no known kind of mathematics which can set up a coordinate system and mathematical equations which will deal with the generalized case of three bodies.

What do scientists actually do when they have to cope with more than two bodies? Newton calculated the orbit of each planet individually, looking only at that planet and the sun. Using what is called perturbation theory, it is possible to do certain mathematical calculations in which we can measure, to some degree of accuracy, the disturbance in the orbit of Mars, for example, when it comes too close to Jupiter, whose gravitational pull is not nearly as great as that of the sun's, but does have a measurable effect.

One can only go so far with this kind of calculation, and the fact that it can be carried out at all is based upon the fact that calculating the interaction between Mars and the sun will give one a very accurate first order approximation, whereas the influence of Jupiter on the orbit of Mars will only be very tiny. And calculations of this sort ultimately become approximations rather than mathematically exact.

There is no known system of mathematics which will enable one to calculate the interactions of all the molecules in the human body, let alone the interactions of all the subatomic particles which make up the molecules in the human body. It is not a matter of not having a big enough computer or enough time to do all the calculations. It is just purely and simply impossible to do so, on the ground of basic mathematical theory. And yet I have read the works of hundreds of philosophers of science blithely going on about how we could carry out these calculations and *prove* that everything that human beings say and do is predictable by the iron law of determinism, moving implacably according to the laws of modern physics.

Philosophers who try to defend that kind of determinism usually at this point say, "Ah yes, but in principle it could be done." No, *in principle* it cannot possibly be done. That is the point: the basic principles of mathematics themselves render this kind of all-inclusive explanation totally impossible. Laplace's Demon is not science, but myth — and wishful thinking and fuzzy logic and evasive game playing — invoked by people who in their hearts do not want to give up the fantasy of someday being able to become masters of the universe.

Situations in which we can totally and exhaustively predict the outcome of natural events occur only in certain kinds of carefully controlled situations, where the number of variables can be artificially constrained and thereby rigorously pruned down. And this applies not only to physics, but to all the other natural sciences, and to the social sciences like psychology and sociology as well.

The Heisenberg uncertainty principle

In 1927, the German physicist Werner Heisenberg (1901-1976) discovered the uncertainty principle. Attempting to determine simultaneously certain kinds of paired quantities, such as for example both the position and momentum of a particle, results in an unavoidable uncertainty. This can be derived directly from the axioms of quantum mechanics, where the uncertainties are a necessary consequence of the way the mathematical quantities themselves have to be defined.

I mention this, because popular interpretations of the Heisenberg uncertainty principle still sometimes confuse this with what is called the observer effect. This latter refers to situations in which the very act of observing a phenomenon will change the nature of the phenomenon being observed. So for example, if we attempted to see an electron, a photon would have to strike the electron, which would change the path and energy level of the electron. So the electron that we thought we "saw" would not be the electron that was there before we altered the situation.

The uncertainty principle could not be gotten around, however, by attempts to observe a situation by even the most subtle means. No matter what pains we went to in our effort to avoid disturbing the phenomenon in the process of observing it, the uncertainty principle would still block us from exact knowledge of many quantities at the atomic and subatomic level.

Chaos and the butterfly effect

In the eighteenth and early nineteenth century, the kind of physics that Newton and Laplace developed focused itself on deterministic situations in which the laws of science could precisely predict the course of events, such as calculating the orbit of the planet Mars around the Sun, or the trajectory of a cannonball fired from a cannon. In the later nineteenth century, statistical thermodynamics was developed, which allowed scientists to describe systems such as the molecules of a gas in a closed container, working on the assumption that the bouncing of the molecules off one another (and the walls of the vessel) were purely random, and followed the normal laws of chance. But there are physical phenomena which are neither rigidly determined nor purely controlled by chance, at least in any way where we can deal statistically with large numbers of events in situations where all we are interested in is the cumulative effect of all the incidents.

These are called chaotic situations. One example would be the places where the smooth flow of air over an airplane's wing is thrown into turbulence at one or more points, as a consequence of some factor in the shape of the airfoil. This can seriously affect the lift and performance of the wing, so aeronautical engineers have to determine in wind tunnels where excessive turbulence appears with their most recent airfoil design, and then they have to figure out how to modify its shape to remove as much of the turbulence as possible. The problem they face is that neither deterministic equations nor statistical analyses will help them.

Another example would be a man who stands on top of a mountain, and takes a large stone and starts it rolling down the mountain. Even very tiny differences between how the man pushes the two different stones, and the exact places at which each stone hits as it bounces down the uneven surface of the mountain, can cause the two stones to end up at the bottom of the mountain in completely different places.

Chaotic processes are those in which tiny differences early in the process can have major effects by the end of the process, effects which are all out of proportion to the initiating cause.

This is sometimes referred to as the butterfly effect, because of the speeches and articles of an American mathematician and meteorologist named Edward Lorenz who showed the power of this effect. Lorenz was going to make another trial run of a computer model which he had developed for predicting the weather, and since all he wanted at that point was a rough calculation, instead of entering the precise figure of 0.506127 at one place, he just typed in 0.506 and left it at that. To his surprise, the kind of weather that it predicted was totally different from what it had predicted when the exact figure had been used, even though the two figures only differed by 0.025 percent. When he published his discovery in a paper for the New York Academy of Sciences in 1963, he commented that one of his fellow meteorologists had remarked to him that, "if the theory were correct, one flap of a seagull's wings could change the course of weather forever." In later years, Lorenz changed the metaphor slightly, and began speaking of butterflies instead of seagulls. When he gave a talk at the meeting of the American Association for the Advancement of

Science in 1972, it was given the title, “Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?”

How does this apply to the topic we are pursuing in this chapter? If Laplace’s Demon were to try to describe the future course of the universe down to the tiniest detail, once he got down to the atomic and subatomic level, he would be confronted with Heisenberg’s uncertainty principle, and would find himself unable to predict exactly how the atoms and subatomic particles were going to interact with one another, and what their paths were going to be. And if Laplace’s Demon had attempted, shortly after the Big Bang, to predict all the details of the universe which was going to emerge, this was a chaotic situation through and through. A single collision between two particles at that point — a collision whose outcome could never be precisely predicted on the grounds of the uncertainty principle — could at times have put one of the galaxies which developed later on in a totally different part of the universe.

Gödel’s proof

There is another reason why Laplace’s Demon cannot predict future states of the universe, which links with the very foundations of mathematics, and does so at the most fundamental level. This is based on what is called Gödel’s proof.

Kurt Gödel (1906-1978) was an Austrian mathematician who published his famous theorems (there were actually two of them) in 1931, when he was only twenty-five years old. In 1940 he came to the Institute for Advanced Study in Princeton, New Jersey, where he and Albert Einstein became close friends, walking to and from the Institute every day until Einstein's death in 1955. Gödel seems to have been one of the few people whose mind and brilliance awed even Einstein.

Gödel's *first incompleteness theorem* has become one of the most famous statements within the field of modern mathematical logic:

> For any consistent formal, computably enumerable theory that proves basic arithmetical truths, an arithmetical statement that is true, but not provable in the theory, can be constructed. That is, any effectively generated theory capable of expressing elementary arithmetic cannot be both consistent and complete.

The kind of theory which Gödel was talking about was constructed by taking a set of starting axioms, which were assumed to be true, and then using those to derive any required number of theorems using standard first-order logic. A theory is consistent if no contradictions can be proven. Gödel confined his theorem to what he called elementary arithmetic, which meant adding and multiplying the natural numbers.

But his proof showed that there *are* no formal systems of the sort he was describing which are both *consistent* (involving no internal contradictions) and *complete* (allowing one to derive all possible true statements from the starting axioms in mechanical fashion).

Gödel's *second theorem* stated in effect that any axiomatic system which can be proven to be consistent and complete from within itself, can be shown on those very grounds to be inconsistent.

Why is this so important? In order for Laplace's Demon to predict the entire future of the universe exhaustively, its vast intellect has to have a formula into which it can place all of the data about the present state of the universe, and this formal theory which the Demon uses in turn has to be used for mathematical calculations, using fundamental mathematical principles which are — so Gödel’s proof shows — by necessity neither consistent nor complete.

If the basic math itself is neither consistent nor complete, the Demon’s calculations using it can be neither consistent nor complete. Ergo, there can be no exhaustive prediction of the entire future of the universe using elementary arithmetic (adding and multiplying the natural numbers). All mathematical formulas used in physics require the use of elementary arithmetic (and much more besides) to make their calculations.

Stephen Hawking

Now Gödel’s proof was, in itself, only applicable to the narrowly defined area of elementary arithmetic. But as other researchers began to think about the full implications of Gödel’s proof, they began to realize that his basic conclusions could be extended to many different kinds of formal systems in addition to elementary arithmetic.

One of the most famous living theoretical physicists, Stephen Hawking, has written on these implications. Hawking (who was born in 1942) was educated at Oxford University and, in spite of being almost totally physically disabled by amyotrophic lateral sclerosis (Lou Gehrig's Disease), is now Lucasian Professor of Mathematics at the University of Cambridge. He is one of the great heroes of the ability of the determined mind to triumph over the infirmities of the body. In his lecture “Gödel and the End of Physics,”[2] he begins by describing the fundamental idea of scientific determinism which the theory of Laplace's Demon expressed:

> If at one time, one knew the positions and velocities of all the particles in the universe, the laws of science should enable us to calculate their positions and velocities, at any other time, past or future. The laws may or may not have been ordained by God, but scientific determinism asserts that he does not intervene, to break them.

But the problem, as Hawking indicates, lies in the simple question, "will we ever find a complete form of the laws of nature?" Because otherwise Laplace's Demon cannot carry out the necessary calculations. And not only do we have to find the ultimate overarching law of physics, this law has to give precise and unambiguous mathematical answers. And already by the beginning of the twentieth century, some of the most important discoveries of modern physics had begun to cast doubt upon our ability to even devise laws which would give specific answers instead of mere probabilities and ranges of possible answers:

> At first, it seemed that these hopes for a complete determinism would be dashed, by the discovery early in the 20th century, that events like the decay of radio active atoms, seemed to take place at random. It was as if God was playing dice, in Einstein's phrase.

Although many philosophers still seem unaware of this, the physicists simply abandoned the claim, at that point in the early twentieth century, that the laws of nature necessarily gave precise and unambiguous predictions of the future. Or as Hawking put it:

> Science snatched victory from the jaws of defeat, by moving the goal posts, and redefining what is meant by a complete knowledge of the universe.

Quantum theory, as developed by Paul Dirac (1902-1984), no longer attempted to describe a particle by its position and velocity in the primary equations which the physicist used, but instead characterized it as a wave function. Dirac, whom Hawking greatly admired, was one of his predecessors as Lucasian Professor of Mathematics at the University of Cambridge, although as Hawking quipped in his lecture, Dirac's professorial chair was not motorized like his!

Now if Dirac's wave function sharply peaked at one point, one could at least state that there was little uncertainty as to its position. But if the wave function was varying rapidly, one was still left with a good deal of uncertainty as to its velocity. So at one level, one could say that physics still provided for a deterministic picture of the universe. We knew with absolute certainty the wave equation which was describing an individual particle. But once one attempted to ask the practical question once again, as to exactly where the particle was at this moment, and how fast it was moving, the uncertainty principle blocked us from knowing both (in particular) with any kind of absolute certitude.

Nevertheless, modern physics has advanced so far, that we can perhaps say that Maxwell's equations describing the nature of light, and the Dirac equation (the relativistic wave equation) "govern most of physics, and all of chemistry and biology."

> So in principle, we ought to be able to predict human behavior, though I can't say I have had much success myself. The trouble is that the human brain contains far too many particles, for us to be able to solve the equations. But it is comforting to think we might be able to predict the nematode worm, even if we can't quite figure out humans.

And as an outstanding issue, there are still important areas of physics which we cannot integrate into our knowledge of other areas of physics. The weak nuclear forces have been unified with the Maxwell equations by the electroweak theory, but the strong nuclear forces can still not be brought into a single unified theory with the other fundamental forces which describe the interactions between subatomic particles. And the force of gravity still has to be described by physicists using Einstein's general theory of relativity, which is not a quantum theory. Nevertheless, Hawking said,

> Up to now, most people have implicitly assumed that there is an ultimate theory, that we will eventually discover. Indeed, I myself have suggested we might find it quite soon. However, M-theory has made me wonder if this is true. Maybe it is not possible to formulate the theory of the universe in a finite number of statements. This is very reminiscent of Gödel's theorem. This says that any finite system of axioms, is not sufficient to prove every result in mathematics.

And even if we could in fact come up with some sort of unified field theory or force theory which would give us a single fundamental formula which would unify all the other laws of physics — which physicists have still not accomplished — with the idea that this might allow Laplace's Demon to totally predict the future in completely deterministic manner, we would still be confronted with the underlying problem raised by Gödel's proof:

> According to the positivist philosophy of science, a physical theory, is a mathematical model. So if there are mathematical results that cannot be proved, there are physical problems that cannot be predicted.

But even beyond that point, as Hawking pointed out, the basic principles behind Gödel's proof would seem to be potentially applicable to any kind of sufficiently complicated formal system, and not just elementary arithmetic alone. There is a good deal of evidence pointing to the possibility that an ultimate theory of science that could be formulated in a finite number of principles — the central goal of modern theoretical physics — might well be subject to the same limitations that Gödel proved applied to the foundations of mathematics. That is, it is entirely possible that *there can be no set of laws of physics* which will be both *consistent* (involving no internal contradictions) and *complete* (allowing one to derive all possible true statements from the starting axioms in mechanical fashion).

The Cretan paradox and self-referential statements

As Hawking point out, Gödel's theorem is proved using statements which refer to themselves. Self-referential statements can easily become insoluble paradoxes. Hawking gave the example of the simple phrase, "this statement is false." If it is true it is false, and vice versa. Another example Hawking gave was what philosophers call the barber paradox. Suppose we claim:

> "The barber of Corfu shaves every man who does not shave himself." Who shaves the barber? If he shaves himself, then he doesn't, and if he doesn't, then he does.

One could argue in fact that Gödel's proof was in many ways simply a more sophisticated version of one especially important ancient Greek paradox, called the Epimenides paradox or Cretan paradox, whose author was a philosopher who lived on the island of Crete somewhere around 600 B.C. This philosopher, Epimenides, made a reference at one point to "the Cretans, always liars." The logical problem with that statement was that Epimenides himself was a Cretan, so that if the Cretans always lied, this statement was also a lie, which meant that the Cretans were not in fact always liars.

The problem for theories of physics, as Hawking pointed out, was that the physicists who devised them were part of the universe they were attempting to describe, which meant that all of the truly basic laws of physics were self-referential statements. As Hawking put it:

> In the standard positivist approach to the philosophy of science, physical theories live rent free in a Platonic heaven of ideal mathematical models. That is, a model can be arbitrarily detailed, and can contain an arbitrary amount of information, without affecting the universes they describe. But we are not angels, who view the universe from the outside. Instead, we and our models, are both part of the universe we are describing. Thus a physical theory is self referencing like in Gödel's theorem. One might therefore expect it to be either inconsistent, or incomplete. The theories we have so far, are — both inconsistent, and incomplete!

Faced with this possibility, Hawking's reaction was, interestingly enough, not despair. Instead he chose to embrace the point of view we saw in Charles Hartshorne's philosophy. A universe which, instead of being rigidly deterministic, provides for novelty and unpredictability can actually be a good deal more interesting kind of universe to live in, because it allows the adventure of our lives and our intellectual pursuits to go on without bounds or limit:

> Some people will be very disappointed if there is not an ultimate theory, that can be formulated as a finite number of principles. I used to belong to that camp, but I have changed my mind. I'm now glad that our search for understanding will never come to an end, and that we will always have the challenge of new discovery. Without it, we would stagnate. Gödel's theorem ensured there would always be a job for mathematicians.

If modern physicists likewise, Hawking said, find themselves with the same kind of open-ended universe of continual new challenges and continual new discoveries, he thought that they would ultimately find it exciting and invigorating. And speaking particularly of the great mathematical physicists of the past, Hawking said, "I'm sure Dirac would have approved."

Gödel and the nature of intelligence itself

In the field of computer science and artificial intelligence, Douglas R. Hofstadter, in his book *Gödel, Escher, Bach*, which won the Pulitzer Prize in 1980, explored a variety of ways in which the Gödel paradox intruded itself into any kind of sequence of logical thought, once the thinker began asking self-referential questions.[3] Hofstadter made the same basic observation that Hawking made, that is, he pointed out how the basic principles inherent in Gödel's proof applied to much more than simply a few little odd philosophical paradoxes.

The human brain, and any kind of true artificial intelligence that the computer experts could build, would of necessity have to be capable of both asking and answering questions, not just about the external world, but also about itself. But the moment any kind of intelligence (whether human or artificial) begins asking self-referential questions — that is, asking questions about itself and the characteristics and logical framework of its own thought processes — the puzzles start to appear. As Hofstadter indicates in numerous examples in *Gödel, Escher, Bach*, the thinker becomes mired in questions to which the rules of his thought processes give "yes" and "no" as equally logical answers. He finds statements where he can correctly deduce from starting principles that they are either "true" or "false" with equal ease. Both can be proven true within that particular system of thought. Immanuel Kant discovered some of these, and called them the antinomies of the human reason and attempted to resolve them, but in fact if we apply the principles of Gödel's proof, we can discover antinomies that are unresolvable.

And as Hofstadter showed, when self-referential questions are not giving us self-contradictory answers, they all too often send us down a path of infinite regress. Each apparent answer to the question requires that I ask yet one more question before a conclusive answer can be given, in an unending process that will never find an end.

Or in other words, Laplace's Demon has more than one problem. First, he is confronted with a universe in which Gödel's proof prevents him from ever coming up with a fully consistent and complete set of all the laws of science. But second, the Demon's very own thought processes are also affected by Gödel's proof, in such a way that as he continues to calculate the future state of the universe, he will find his own thought processes either giving him contradictory answers or sending him down infinite regresses of questions upon questions, to which no final answer will ever be given.

Information theory

As long as we are discussing the matter of pseudo-infinite regresses, it would be useful here to explain yet another reason why Laplace's Demon can never finish his task, and can never give us a complete and consistent account of why all the things that exist in the universe are as they are and could be no other way.

Information theory was another of those marvelous sets of discoveries that took place during the twentieth century, which have so greatly changed our view of the world. It initially arose in the study of the engineering problem of the transmission of information over a noisy channel. Its origins lay in an article entitled “A Mathematical Theory of Communication,” which was published in 1948 by an American electrical engineer and mathematician named Claude E. Shannon (1916-2001) who was working at the Bell Telephone Laboratories.[4]

Just like physical objects — where we can use numbers to specify the length and height and thickness of an object, and its mass — information also has a “size.” Shannon used the word “bit” in his famous paper (a shortened form of the phrase “binary digit”) to refer to the basic unit of information. The bit is the amount of information which we obtain when we learn which one of two equally probable alternatives is true. In binary computer language, the two alternatives are represented as either 0 or 1. So if we look at a computer calculation in the form in which it is actually computed within the processor, we will see a string of 1’s and 0’s (perhaps something like 00101110100010), where each 1 or 0 represents one bit of information.

A bit of information is so small, that in the development of modern computer terminology, a larger unit was eventually devised, called a Byte, which at present is usually equal to 8 bits (this is because at one point in twentieth century computer development it took roughly eight bits to encode a single letter of the alphabet). As computers got larger and larger, bigger units had to be devised, so at present a kiloByte is a thousand Bytes, a megaByte is a thousand kiloBytes, a gigaByte is a thousand megaBytes, and so on.

But to return to Laplace's Demon. Let us give the one who is doing this calculation every help that we possibly can, so let us imagine that it is a God who is attempting to predict the future. Being a God, he has no problem determining all of the necessary data about every single particle and wave and field in the entire universe external to himself, and also knows all of the laws of nature and the mathematical and logical theories required to apply these laws. This represents such an enormous amount of information, that we will have to devise an extremely large unit of measure to describe it in information theory. Let us measure God's knowledge of the universe in GodzillaBytes.

In the Western European Middle Ages, and particularly in the High Calvinism which developed in parts of Western Europe and North America during the Early Modern Period, it was believed that God had already foreseen everything that was going to happen before he even created the universe. God already knew that Adam and Eve were going to eat the forbidden fruit and that it was going to be necessary to send Christ to get the human race back on track. He knew in advance who would win every Indiana University basketball game and every University of Notre Dame football game for the entire course of the twentieth century and beyond. He also knew exactly what each human being who was ever going to live was going to do through the entire course of that person's life. Some human beings were going to be created for redemption, while others were going to be created for damnation. The question of whether any individual human being was going to be saved or damned was the result of an arbitrary divine decree, in such a way that human beings had no free will at all on that issue. (In High Calvinistic theology, that was called a doctrine of geminal supralapsarian predestination, and was believed to be the only orthodox position.)

But let us look a little more carefully, and see whether this would all be possible. In this kind of Calvinism, human beings may not have any real free will (or at least the way a good many of us would define that), but God has free will. So in between doing these calculations and actually creating the universe, God could change his mind about something. It might only be a small thing: letting the Indiana University basketball team win one game they had previously been foreordained to lose, or saving the soul of some poor man or woman instead of damning that person to eternal hell. Also, the Calvinist God is not only omniscient (all-knowing) but also omnipotent (all-powerful). So he could decide, if he wanted to, even after the universe had already been created, to alter the course of events. In fact this seems to be almost a necessary power to give him. What would be the point of praying to God, if it were not possible for him to change what was otherwise going to happen?

But this raises a major problem. This God cannot predict in advance exactly what is going to happen at all future stages of the universe, because he himself is an actor in that sequence of events. So we will need to come up with a meta-God to calculate what this God is going to do. Now if the amount of information needed to describe all the data in the universe is 10 GodzillaBytes, the Calvinist God will have to contain at least 10 GodzillaBytes of information just to store all that data in his divine memory. So our meta-God will need to have a memory capacity of at least twice that amount: 10 GodzillaBytes of information about the universe, plus an additional 10 GodzillaBytes of information about God, for a total of 20 GodzillaBytes of information at a bare minimum (actually much more, in order to carry out the processing of all this information).

I think the reader can see the next problem at this point. The meta-God is also part of the overall equation (this is what is called the observer effect, which we mentioned earlier, which is not the same as the Heisenberg uncertainty principle, but can introduce similar kinds of problems). So we will also need a meta-meta-God to tell us what the meta-God is going to do. And this meta-meta-God will need over 30 GodzillaBytes of memory simply to put all of the necessary data about the universe, God, and the meta-God into his information storage system.

But alas, this too will not give us our perfect prediction of the future, so that we will be driven into consulting next a meta-meta-meta-God, and then a meta-meta-meta-meta-God, and so on, in an infinite regress which would go on forever, but never give us the deterministic universe which the theory of Laplace's Demon seems to promise.

Total determinism is an illusion

The idea that one could in principle totally predict the future is an illusion. It is a harmless illusion when it drives scientists on to solve yet more problems and devise better and better theories. But it becomes a dangerous illusion when we begin believing that we live in what is only a mechanical, totally deterministic universe. The real universe is one in which human beings are oftentimes at the mercy of forces they cannot control, but they must never forget that they are also granted, here and there, moments of true freedom. That means that they are morally responsible for what they make of their lives.

And above all, the real universe is one where there is not only enormous goodness and beauty and holiness, but also real novelty and the opportunity for genuine creativity. Time is not the mechanical ticking and grinding of a clockwork mechanism, where I am forced to run along a predetermined track set for me by the blind forces of subhuman nature, but a journeying forth into a Great Adventure. And as we walk this path, fighting the good fight and seeking ever new horizons, we become true children of the great Alpha and Omega who eternally proclaims (Rev. 21:5-6), "Behold, I make all things new."

NOTES

1. A physicist whom I studied under at Iowa State University devised a way of calculating the orbit of the single outer electron in an ionized molecule of oxygen, where the electron and the two oxygen nuclei formed a three-body system, by using elliptical coordinates where the oxygen nuclei were placed at the two foci of the ellipses. The energy levels of the orbits which he and his graduate student calculated in fact matched up with the experimentally observed lines in the spectrum of ionized oxygen. And there are a handful of other kinds of special situations where the equations for a three-body system can be set up and solved. But these are the kinds of exceptions which prove the general rule that a three-body problem cannot be solved.

2. Stephen Hawking, "Gödel and the end of physics," at: http://www.damtp.cam.ac.uk/strings02/dirac/hawking/ (September 2007).

3. Hofstadter, *Gödel, Escher, Bach*.

4. It appeared as a two-part article in the July and October 1948 issues of the *Bell System Technical Journal*.

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