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Philosophy: Stephen Hawking – The Grand Design

If nature is governed by laws, three questions arise:

1. What is the origin of the laws?

2. Are there any exceptions to the laws, i.e., miracles?

3. Is there only one set of possible laws?

These important questions have been addressed in varying ways by scientists, philosophers, and theologians. The answer traditionally given to the first question—the answer of Kepler, Galileo, Descartes, and Newton—was that the laws were the work of God. However, this is no more than a definition of God as the embodiment of the laws of nature. Unless one endows God with some other attributes, such as being the God of the Old Testament, employing God as a response to the first question merely substitutes one mystery for another. So if we involve God in the answer to the first question, the real crunch comes with the second question: Are there miracles, exceptions to the laws?

Opinions about the answer to the second question have been sharply divided. Plato and Aristotle, the most influential ancient Greek writers, held that there can be no exceptions to the laws. But if one takes the biblical view, then God not only created the laws but can be appealed to by prayer to make exceptions—to heal the terminally ill, to bring premature ends to droughts, or to reinstate croquet as an Olympic sport. In opposition to Descartes' view, almost all Christian thinkers maintained that God must be able to suspend the laws to accomplish miracles. Even Newton believed in miracles of a sort. He thought that the orbit of the planets would be unstable because the gravitational attraction of one planet for another would cause disturbances to the orbits that would grow with time and would result in the planets either falling into the sun or being flung out of the solar system. God must keep on resetting the orbits, he believed, or "wind the celestial watch, lest it run down." However, Pierre-Simon, Marquis de Laplace (1749–1827), commonly known as Laplace, argued that the perturbations would be periodic, that is, marked by repeated cycles, rather than being cumulative. The solar system would thus reset itself, and there would be no need for divine intervention to explain why it had survived to the present day.

It is Laplace who is usually credited with first clearly postulating **scientific determinism**: Given the state of the universe at one time, a complete set of laws fully determines both the future and the past. This would exclude the possibility of miracles or an active role for God. The scientific determinism that Laplace formulated is the modern scientist's answer to question two. It is, in fact, the basis of all modern science, and a principle that is important throughout this book. A scientific law is not a scientific law if it holds only when some supernatural being decides not to intervene. Recognizing this, Napoleon is said to have asked Laplace how God fit into this picture. Laplace replied: "Sire, I have not needed that hypothesis."

Since people live in the universe and interact with the other objects in it, scientific determinism must hold for people as well. Many, however, while accepting that scientific determinism governs physical processes, would make an exception for human behavior because they believe we have free will. Descartes, for instance, in order to preserve the idea of free will, asserted that the human mind was something different from the physical world and did not follow its laws. In his view a person consists of two ingredients, a body and a soul. Bodies are nothing but ordinary machines, but the soul is not subject to scientific law.

Descartes was very interested in anatomy and physiology and regarded a tiny organ in the center of the brain, called the pineal gland, as the principal seat of the soul. That gland, he believed, was the place where all our thoughts are formed, the wellspring of our free will.

Do people have free will? If we have free will, where in the evolutionary tree did it develop? Do blue-green algae or bacteria have free will, or is their behavior automatic and within the realm of scientific law? Is it only multicelled organisms that have free will, or only mammals? We might think that a chimpanzee is exercising free will when it chooses to chomp on a banana, or a cat when it rips up your sofa, but what about the roundworm called *Caenorhabditis elegans*—a simple creature made of only 959 cells? It probably never thinks, “That was damn tasty bacteria I got to dine on back there,” yet it too has a definite preference in food and will either settle for an unattractive meal or go foraging for something better, depending on recent experience. Is that the exercise of free will?

Though we feel that we can choose what we do, our understanding of the molecular basis of biology shows that biological processes are governed by the laws of physics and chemistry and therefore are as determined as the orbits of the planets. Recent experiments in neuroscience support the view that it is our physical brain, following the known laws of science, that determines our actions, and not some agency that exists outside those laws. For example, a study of patients undergoing awake brain surgery found that by electrically stimulating the appropriate regions of the brain, one could create in the patient the desire to move the hand, arm, or foot, or to move the lips and talk. It is hard to imagine how free will can operate if our behavior is determined by physical law, so it seems that we are no more than biological machines and that free will is just an illusion.

While conceding that human behavior is indeed determined by the laws of nature, it also seems reasonable to conclude that the outcome is determined in such a complicated way and with so many variables as to make it impossible in practice to predict. For that one would need a knowledge of the initial state of each of the thousand trillion trillion molecules in the human body and to solve something like that number of equations. That would take a few billion years, which would be a bit late to duck when the person opposite aimed a blow.

Because it is so impractical to use the underlying physical laws to predict human behavior, we adopt what is called an effective theory. In physics, an effective theory is a framework created to model certain observed phenomena without describing in detail all of the underlying processes. For example, we cannot solve exactly the equations governing the gravitational interactions of every atom in a person’s body with every atom in the earth. But for all practical purposes the gravitational force between a person and the earth can be described in terms of just a few numbers, such as the person’s total mass. Similarly, we cannot solve the equations governing the behavior of complex atoms and molecules, but we have developed an effective theory called chemistry that provides an adequate explanation of how atoms and molecules behave in chemical reactions without accounting for every detail of the interactions. In the case of people, since we cannot solve the equations that determine our behavior, we use the effective theory that people have free will. The study of our will, and of the behavior that arises from it, is the science of psychology. Economics is also an effective theory, based on the notion of free will plus the assumption that people evaluate their possible alternative courses of action and choose the best. That effective theory is only moderately successful in predicting behavior because, as we all know, decisions are often not rational or are based on a defective analysis of the consequences of the choice. That is why the world is in such a mess.

The third question addresses the issue of whether the laws that determine both the universe and human behavior are unique. If your answer to the first question is that God created the laws, then this question asks: did God have any latitude in choosing them? Both Aristotle and Plato believed, like Descartes and later Einstein, that the principles of nature exist out of “necessity,” that is, because they are the only rules that make logical sense. Due to his belief in the origin of the laws of nature in logic, Aristotle and his followers felt that one could “derive” those laws without paying a lot of attention to how nature actually behaved. That, and the focus on why objects follow rules rather than on the specifics of what the rules are, led him to mainly qualitative laws that were often wrong and in any case did not prove very useful, even if they did dominate scientific thought for many centuries. It was only much later that people such as Galileo dared to challenge the authority of Aristotle and observe what nature actually did, rather than what pure “reason” said it ought to do.

This book is rooted in the concept of scientific determinism, which implies that the answer to question two is that there are no miracles, or exceptions to the laws of nature. We will, however, return to address in depth questions one and three, the issues of how the laws arose and whether they are the only possible laws. But first, in the next chapter, we will address the issue of what it is that the laws of nature describe. Most scientists would say they are the mathematical reflection of an external reality that exists independent of the observer who sees it. But as we ponder the manner in which we observe and form concepts about our surroundings, we bump into the question: do we really have reason to believe that an objective reality exists?

A few years ago the city council of Monza, Italy, barred pet owners from keeping goldfish in curved goldfish bowls. The measure’s sponsor explained the measure in part by saying that it is cruel to keep a fish in a bowl with curved sides because, gazing out, the fish would have a distorted view of reality. But how do we know we have the true, undistorted picture of reality? Might not we ourselves also be inside some big goldfish bowl and have our vision distorted by an enormous lens? The goldfish’s picture of reality is different from ours, but can we be sure it is less real?

The goldfish view is not the same as our own, but goldfish could still formulate scientific laws governing the motion of the objects they observe outside their bowl. For example, due to the distortion, a freely moving object that we would observe to move in a straight line would be observed by the goldfish to move along a curved path. Nevertheless, the goldfish could formulate scientific laws from their distorted frame of reference that would always hold true and that would enable them to make predictions about the future motion of objects outside the bowl. Their laws would be more complicated than the laws in our frame, but simplicity is a matter of taste. If a goldfish formulated such a theory, we would have to admit the goldfish’s view as a valid picture of reality.

A famous example of different pictures of reality is the model introduced around AD 150 by Ptolemy (ca. 85—ca. 165) to describe the motion of the celestial bodies. Ptolemy published his work in a thirteen-book treatise usually known under its Arabic title, *Almagest.* The *Almagest* begins by explaining reasons for thinking that the earth is spherical, motionless, positioned at the center of the universe, and negligibly small in comparison to the distance of the heavens. Despite Aristarchus’s heliocentric model, these beliefs had been held by most educated Greeks at least since the time of Aristotle, who believed for mystical reasons that the earth should be at the center of the universe. In Ptolemy’s model the earth stood still at the center and the planets and the stars moved around it in complicated orbits involving epicycles, like wheels on wheels.

This model seemed natural because we don’t feel the earth under our feet moving (except in earthquakes or moments of passion). Later European learning was based on the Greek sources that had been passed down, so that the ideas of Aristotle and Ptolemy became the basis for much of Western thought. Ptolemy’s model of the cosmos was adopted by the Catholic Church and held as official doctrine for fourteen hundred years. It was not until 1543 that an alternative model was put forward by Copernicus in his book *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*), published only in the year of his death (though he had worked on his theory for several decades).

Copernicus, like Aristarchus some seventeen centuries earlier, described a world in which the sun was at rest and the planets revolved around it in circular orbits. Though the idea wasn't new, its revival was met with passionate resistance. The Copernican model was held to contradict the Bible, which was interpreted as saying that the planets moved around the earth, even though the Bible never clearly stated that. In fact, at the time the Bible was written people believed the earth was flat. The Copernican model led to a furious debate as to whether the earth was at rest, culminating in Galileo's trial for heresy in 1633 for advocating the Copernican model, and for thinking "that one may hold and defend as probable an opinion after it has been declared and defined contrary to the Holy Scripture." He was found guilty, confined to house arrest for the rest of his life, and forced to recant. He is said to have muttered under his breath "*Eppur si muove,*" "But still it moves." In 1992 the Roman Catholic Church finally acknowledged that it had been wrong to condemn Galileo.

So which is real, the Ptolemaic or Copernican system? Although it is not uncommon for people to say that Copernicus proved Ptolemy wrong, that is not true. As in the case of our normal view versus that of the goldfish, one can use either picture as a model of the universe, for our observations of the heavens can be explained by assuming either the earth or the sun to be at rest. Despite its role in philosophical debates over the nature of our universe, the real advantage of the Copernican system is simply that the equations of motion are much simpler in the frame of reference in which the sun is at rest.

A different kind of alternative reality occurs in the science fiction film *The Matrix,* in which the human race is unknowingly living in a simulated virtual reality created by intelligent computers to keep them pacified and content while the computers suck their bioelectrical energy (whatever that is). Maybe this is not so far-fetched, because many people prefer to spend their time in the simulated reality of websites such as Second Life. How do we know we are not just characters in a computer-generated soap opera? If we lived in a synthetic imaginary world, events would not necessarily have any logic or consistency or obey any laws. The aliens in control might find it more interesting or amusing to see our reactions, for example, if the full moon split in half, or everyone in the world on a diet developed an uncontrollable craving for banana cream pie. But if the aliens did enforce consistent laws, there is no way we could tell there was another reality behind the simulated one. It would be easy to call the world the aliens live in the "real" one and the synthetic world a "false" one. But if—like us—the beings in the simulated world could not gaze into their universe from the outside, there would be no reason for them to doubt their own pictures of reality. This is a modern version of the idea that we are all figments of someone else's dream. These examples bring us to a conclusion that will be important in this book: *There is no picture- or theory-independent concept of reality.* Instead we will adopt a view that we will call model-dependent realism: the idea that a physical theory or world picture is a model (generally of a mathematical nature) and a set of rules that connect the elements of the model to observations. This provides a framework with which to interpret modern science.

Philosophers from Plato onward have argued over the years about the nature of reality. Classical science is based on the belief that there exists a real external world whose properties are definite and independent of the observer who perceives them. According to classical science, certain objects exist and have physical properties, such as speed and mass, that have well-defined values. In this view our theories are attempts to describe those objects and their properties, and our measurements and perceptions correspond to them. Both observer and observed are parts of a world that has an objective existence, and any distinction between them has no meaningful significance. In other words, if you see a herd of zebras fighting for a spot in the parking garage, it is because there really is a herd of zebras fighting for a spot in the parking garage. All other observers who look will measure the same properties, and the herd will have those properties whether anyone observes them or not. In philosophy that belief is called realism.

Though realism may be a tempting viewpoint, as we'll see later, what we know about modern physics makes it a difficult one to defend. For example, according to the principles of quantum physics, which is an accurate description of nature, a particle has neither a definite position nor a definite velocity unless and until those quantities are measured by an observer. It is therefore *not* correct to say that a measurement gives a certain result because the quantity being measured had that value at the time of the measurement. In fact, in some cases individual objects don't even have an independent existence but rather exist only as part of an ensemble of many. And if a theory called the holographic principle proves correct, we and our four-dimensional world may be shadows on the boundary of a larger, five-dimensional space-time. In that case, our status in the universe is analogous to that of the goldfish.

Strict realists often argue that the proof that scientific theories represent reality lies in their success. But different theories can successfully describe the same phenomenon through disparate conceptual frameworks. In fact, many scientific theories that had proven successful were later replaced by other, equally successful theories based on wholly new concepts of reality.

Traditionally those who didn't accept realism have been called anti-realists. Anti-realists suppose a distinction between empirical knowledge and theoretical knowledge. They typically argue that observation and experiment are meaningful but that theories are no more than useful instruments that do not embody any deeper truths underlying the observed phenomena. Some anti-realists have even wanted to restrict science to things that can be observed. For that reason, many in the nineteenth century rejected the idea of atoms on the grounds that we would never see one. George Berkeley (1685–1753) even went as far as to say that nothing exists except the mind and its ideas. When a friend remarked to English author and lexicographer Dr. Samuel Johnson (1709–1784) that Berkeley's claim could not possibly be refuted, Johnson is said to have responded by walking over to a large stone, kicking it, and proclaiming, "I refute it thus." Of course the pain Dr. Johnson experienced in his foot was also an idea in his mind, so he wasn't really refuting Berkeley's ideas. But his act did illustrate the view of philosopher David Hume (1711–1776), who wrote that although we have no rational grounds for believing in an objective reality, we also have no choice but to act as if it is true.

Model-dependent realism short-circuits all this argument and discussion between the realist and anti-realist schools of thought. According to model-dependent realism, it is pointless to ask whether a model is real, only whether it agrees with observation. If there are two models that both agree with observation, like the goldfish's picture and ours, then one cannot say that one is more real than another. One can use whichever model is more convenient in the situation under consideration. For example, if one were inside the bowl, the goldfish's picture would be useful, but for those outside, it would be very awkward to describe events from a distant galaxy in the frame of a bowl on earth, especially because the bowl would be moving as the earth orbits the sun and spins on its axis.

We make models in science, but we also make them in everyday life. Model-dependent realism applies not only to scientific models but also to the conscious and subconscious mental models we all create in order to interpret and understand the everyday world. There is no way to remove the observer—us—from our perception of the world, which is created through our sensory processing and through the way we think and reason. Our perception—and hence the observations upon which our theories are based—is not direct, but rather is shaped by a kind of lens, the interpretive structure of our human brains.

Model-dependent realism corresponds to the way we perceive objects. In vision, one's brain receives a series of signals down the optic nerve. Those signals do not constitute the sort of image you would accept on your television. There is a blind spot where the optic nerve attaches to the retina, and the only part of your field of vision with good resolution is a narrow area of about 1 degree of visual angle around the retina’s center, an area the width of your thumb when held at arm’s length. And so the raw data sent to the brain are like a badly pixilated picture with a hole in it. Fortunately, the human brain processes that data, combining the input from both eyes, filling in gaps on the assumption that the visual properties of neighboring locations are similar and interpolating. Moreover, it reads a two-dimensional array of data from the retina and creates from it the impression of three-dimensional space. The brain, in other words, builds a mental picture or model.

The brain is so good at model building that if people are fitted with glasses that turn the images in their eyes upside down, their brains, after a time, change the model so that they again see things the right way up. If the glasses are then removed, they see the world upside down for a while, then again adapt. This shows that what one means when one says “I see a chair” is merely that one has used the light scattered by the chair to build a mental image or model of the chair. If the model is upside down, with luck one’s brain will correct it before one tries to sit on the chair.

Another problem that model-dependent realism solves, or at least avoids, is the meaning of existence. How do I know that a table still exists if I go out of the room and can’t see it? What does it mean to say that things we can’t see, such as electrons or quarks—the particles that are said to make up the proton and neutron—exist? One could have a model in which the table disappears when I leave the room and reappears in the same position when I come back, but that would be awkward, and what if something happened when I was out, like the ceiling falling in? How, under the table-disappears-when-I-leave-the-room model, could I account for the fact that the next time I enter, the table reappears broken, under the debris of the ceiling? The model in which the table stays put is much simpler and agrees with observation. That is all one can ask.