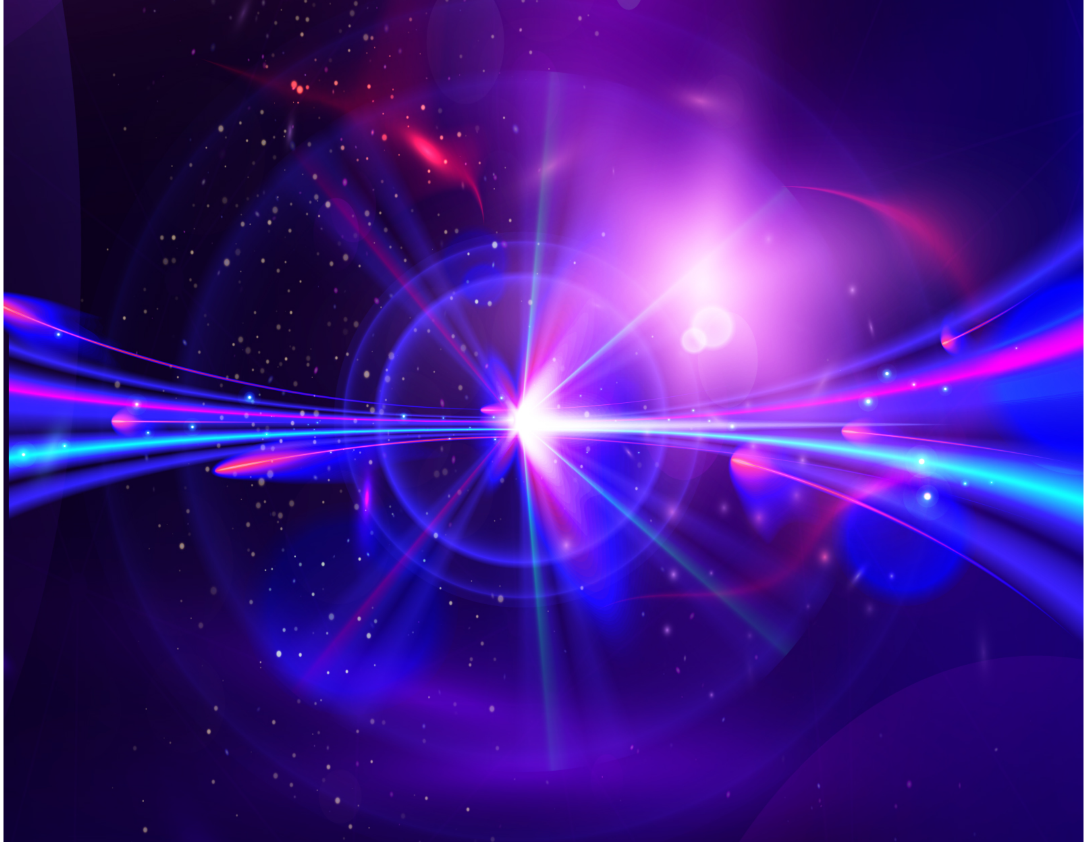
SUMMARY

THE GRAND DESIGN

STEPHEN HAWKING, LEONARD MLODINOW



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Summary of “The Grand Design” by Stephen Hawking and Leonard Mlodinow

Written by Lea Schullery

Learn About the Mysteries of the Universe

Introduction

Humans are a curious species. As we go through our short existence, we wonder and we seek answers. We gaze at the sky above us and ask a multitude of questions, like *how can we understand the world? How does the universe behave? Where did all this come from? Do we have a creator?* In the past, humans answered these questions by using gods to explain the world's natural phenomena. For example, in Viking Mythology, wolves named Skoll and Hati lived in the sky and chased the sun and moon. When one wolf caught the other, an eclipse would happen. When this happened, the people on earth would come to the rescue by making as much noise as possible in hopes of scaring off the wolves. Each culture had its own stories to explain the world around them. But over time, humans began to notice that eclipses didn't happen at random; instead, they occurred in regular patterns and repeated themselves. Humans began to realize that eclipses were governed by law.

Today, we know more than ever before about our universe. Now we know how an eclipse happens, and we can even predict when it will happen. Science has made great strides in understanding the vast world of the cosmos, but not only that, scientists understand more about the tiny subatomic particles that make up our universe as well. Throughout *The Grand Design,* authors Stephen Hawking and Leonard Mlodinow explain the most recent scientific thinking about the greatest mysteries of the world. Keep reading to learn how humans are simply a product of quantum fluctuations in the early universe, and how quantum theory predicts the "multiverse," which is the idea that our universe is just one of many that appeared spontaneously out of nothing.

From gods to Scientific Laws

As humans, we are naturally curious about the world. As a result of our curiosity, people in ancient times invented gods to explore almost every aspect of human life. There were gods of love, war, the sun, earth, sky, oceans, rain, thunderstorms, and even earthquakes and volcanoes. They believed that when the gods were pleased, they would become blessed with good weather, peace, and freedom from a natural disaster; however, when they were displeased, they suffered through droughts, wars, pestilence, and epidemics. In other words, humans lived to please the gods and believed natural disasters and epidemics were simply a result of failing to please them.

It wasn't until the "classical period" when ancient Greek philosophers began to develop the idea that the world could be understood, and that the complex happenings around us could be known without resorting to mythological or theological explanations. Thales became the first Greek philosopher to predict a solar eclipse in 585 BC, though his prediction could have also been a lucky guess. Other Greek philosophers like Aristotle and Archimedes also helped to establish laws to help us understand how the world works. Archimedes, for example, was one of the first to conduct experiments and measure the results. His work led to three laws that we know of today as *the law of the lever, the law of buoyancy,* and *the law of reflection.*

In today's terminology, the law of the lever explains that small forces can lift large weights, the law of buoyancy states that an object immersed in a fluid will experience an upward force equal to the weight of the displaced fluid. And the law of reflection explains how an angle between a beam of light and a mirror is equal to the angle between the mirror and the reflected beam. These philosophers, however, had not yet invented the scientific method, so their theories were not developed for experimental verification. In other words, when scientists argued over theories, there was no objective way to settle it.

Then, in the sixteenth and seventeenth centuries, scholars like Galileo and René Descartes began using the scientific method to help explain the world around us. It was Descartes who formulated the concept of laws of nature as we understand them today. He believed that all physical phenomena must be explained in terms of the collisions of moving masses, which were governed by three laws. Those laws then helped Isaac Newton discover the laws of gravity and motion, which ultimately allowed us to understand how the celestial bodies in space moved.

But since we live in the universe as well, are humans subject to the laws of nature as well?

The Existence or Non-Existence of Free Will

As scientists and philosophers learned more about the world, they eventually proposed the concept of scientific determinism, which states that "given the state of the universe at one time, a complete set of laws fully determines both the future and the past." In other words, scientific determinism means that everything in the universe is governed by a set of laws, which also excludes the possibility of miracles or an active role of God. But if everything is governed by laws, scientific determinism must be true for people as well. Does this mean that free will doesn't exist?

Scientists aim to answer this question and have long debated the existence of free will. Descartes was a proponent of free will, for instance, he asserted that the human mind was something entirely different from the physical world; therefore, it does not follow its laws. According to Descartes, a person consists of two ingredients: a body and soul. Bodies are just ordinary machines, but the soul is not subject to scientific law. He even argued that the pineal gland, the tiny organ in the center of the brain, is where the heart of the soul lies. That gland, he believed, housed all of our thoughts and was the source of our free will.

So does free will exist? Well, recent experiments in neuroscience support the view that our physical brain determines our actions and follows the known laws of science, not some agency that exists outside those laws. For example, a study of patients undergoing awake brain surgery found that if you electrically stimulate certain regions of the brain, you could create a desire to move the hand, arm, or foot, or to move the lips and talk. This simply shows that our behavior is determined by physical law, so it seems as if we are no more than biological machines and that free will is just an illusion.

If we concede to the notion that human behavior is determined by laws of nature, we must also conclude that human behavior is impossible to predict. As a result, we must adopt what is called an effective theory. An effective theory is simply a framework created to model certain phenomena without describing in detail the underlying processes. For example, “we cannot solve equations governing the behavior of complex atoms and molecules, but we have an effective theory called chemistry that provides us with an adequate explanation of how atoms and molecules behave in chemical reactions without accounting for every detail of the interactions.”

Similarly, we cannot solve the equations that determine our behavior; therefore, we use the effective theory that people have free will. We have fields like psychology and economics which help to explain human behavior. However, these effective theories are only moderately successful in predicting behavior because our decisions are not rational. Perhaps this is why the world is in such a mess!

Model-Dependent Realism Argues the Existence of Reality

Ever wonder what a goldfish sees from behind the fishbowl? Well, the city council of Monza, Italy once prohibited pet owners from keeping goldfish in curved fishbowls because they believed it was cruel to keep a fish in a bowl with curved sides. They believed the curved glass would give the fish a distorted view of reality. But how do we know that our picture of reality is accurate and not distorted? You see, we believe in our reality because we have created scientific laws that have been accepted as true and accurate. Since our vision adheres to these laws, we accept our reality as being the correct one.

When you look at an object, say a chair, your brain receives a series of signals down to the optic nerve. However, the raw data sent to the brain is filled with holes and becomes like a badly pixilated picture. Fortunately, the human brain processes that data and combines the input from both eyes, filling the gaps on its own. In other words, the brain builds a mental picture or model. The idea that a physical theory or world picture is a model is called *model-dependent realism,* which provides a framework with which to interpret modern science. According to model-dependent realism, we cannot say that one model is more real than another. In other words, we can't say that our view is more real than a goldfish's view from a curved fishbowl.

With model-dependent realism, we must also look at the meaning of existence. How do you know a table still exists if you go out of the room and can't see it? Just because we can't see something doesn't mean it doesn't exist, right? In 1897, British physicist J.J. Thompson was experimenting with currents of electricity inside empty glass tubes, a phenomenon known as cathode rays. As a result of his experiment, Thompson discovered the existence of *electrons*. He did not see electrons, and today all physicists believe in electrons though no one has ever *seen* one.

We also cannot see quarks, which are a model to explain the properties of protons and neutrons. However, we will never observe a quark because quarks increase with separation, so when isolated, free quarks cannot exist in nature. The question of whether or not quarks exist became a controversial issue after the quark model was introduced. Over the years, however, the quark model continued to lead to more and more accurate predictions. As a result, opposition began to fade. Therefore, according to model-dependent realism, quarks exist in a model that agrees with our observations of how subnuclear particles behave.

Lastly, we can use model-dependent realism to provide a framework for discussing questions about the history of the universe. For some, one model suggests that God created the world and that time did not exist before its creation. This model is favored by those who believe that the Bible is true, even though the world contains fossils and other evidence that suggests the world is much older. Therefore, we have a second model that better explains our present observations and uses historical and geological evidence to explain the past. The second model explains fossils, radioactive records, and the fact that we receive light from galaxies millions of light-years from us. This Big Bang theory might be more useful than the first, but still, neither model is said to be more real than the other.

The Components of a Good Model of Reality

With all the different models that exist, it's important to discuss what makes a model a good model. There are four elements to a good model of reality. The first is that the model must be elegant. Elegance may be hard to measure, but it is highly prized among scientists because laws of nature are meant to be compressed into one simple formula. Einstein himself believed that a theory should be as simple as possible, but not simpler, which is why his famous formula $E=MC^2$ is a great example of scientific elegance.

The second element of a good theory is that it contains few arbitrary or adjustable elements. In other words, it would be a bad sign if a theory required too many steps or extra elements to work. For example, Ptolemy added epicycles to the circular orbits of planets to create an accurate model of their movement. While the model was accurate, it could have been made more accurate if Ptolemy added even more epicycles; however, the added complexity would be viewed by scientists as unsatisfying, seeing it more as a catalog of data rather than a theory likely to embody any useful principle.

The third element is that it must agree with and explain all existing observations. For example, consider the theory of light. Newton believed that light was made up of tiny particles called corpuscles. These corpuscles explained why light travels in straight lines, and Newton also used it to explain why light is bent when it passes from one medium to another, like from air to glass. However, this theory couldn't explain why light forms a pattern of rings when reflected between two surfaces, a phenomenon known as Newton's rings. With the particle theory of light, this phenomenon could not be accounted for and difficult to explain; therefore, it wasn't accepted as a scientific law.

Lastly, the fourth element of a good model is that it makes detailed predictions about future observations that can disprove or falsify the model if they are not carried out. For example, we have formulated a number of theories or models that explain the laws that govern the universe. We have the big bang theory, the Ptolemaic model, and more. With each theory or model, our concepts of reality and of the fundamental components of the universe have changed. You see, while Newton's theory of light failed to explain the pattern of rings, the theory made way for a new theory: wave theory. According to the wave theory of light, light and dark rings are caused by a phenomenon called *interference*.

When you imagine a wave, you see that each wave consists of a series of crests and troughs. When those waves collide, the crests and troughs can reinforce one another, creating a larger wave. This is called *constructive interference*. On the other hand, the crests and troughs can cancel each other out, this is called *destructive interference*. In Newton's rings, the bright and dark rings can be explained as reflections that cause constructive and destructive interferences. This wave theory of light showed that particle theory was wrong. However, Einstein proved in the early twentieth century that light behaves as both particle and wave, and Newton's theories of light were expanded upon once again.

Quantum Physics Helps Us Understand the World's Elementary Particles

In the first two thousand years or so of scientific thought, the bulk of theoretical explanations were based on ordinary experience and intuition. But as we improved our technology and expanded our range of knowledge, we began to find that nature behaved in ways that contradicted our everyday experiences and our intuition. Today, we have quantum physics to help explain the phenomena that we cannot necessarily see and provides a framework for understanding how nature operates on atomic and subatomic scales.

One of the main tenants of quantum physics is the uncertainty principle. Formulated by Werner Heisenburg in 1926, “the uncertainty principle tells us that there are limits to our ability to simultaneously measure certain data, such as the position and velocity of a particle.” Heisenberg found that the more precisely you measure the speed of a particle, the less precisely you can measure position, and vice versa. In other words, we cannot know where a particle has been or predict where it will be in the future. This idea has led to the laws of nature which determine the *probabilities* of various futures and pasts rather than determining the future and past with certainty.

Another key quantum principle is that “observing a system must alter its course.” In other words, according to quantum physics, you cannot simply observe something without interacting with the object you are observing. For example, to see an object in the traditional sense, you must shine a light on it. Shining a light on something, like a pumpkin, will have little effect on it. But shining even a dim light on a tiny quantum particle will shoot protons onto the object, thus affecting it greatly. So while light won’t affect large objects, like pumpkins, it will have a great effect on tiny particles.

Simply put, particles don’t have a single history, but several possible histories, each with its own probability. Like particles, the universe doesn’t have a single history either, and our observations of the current universe affect its past and determine the different histories. As a result, we will see how laws of nature in our universe arose from the big bang, but before we discuss how those laws arose, we will need to discuss what those laws are.

Einstein's Theories of Special Relativity and General Relativity

The universe is comprehensible because it is governed by scientific laws. In other words, its behavior can be modeled. But what are these laws or models? One of the first forces described in mathematical language was Newton’s law of gravity, published in 1687, which stated that every object in the universe attracts every other object due to an invisible force called gravity. But perhaps some of the most important discoveries about our universe came from Albert Einstein, who at just 26-years-old published his first paper on the now-famous Theory of Special Relativity.

With this theory, Einstein revolutionized what we know about time and space. Begin by imagining traveling on an airplane in which you observe a pulse of light traveling from the tail of the aircraft to the nose. Your observation of the light will differ from a person who also observes the light from the ground. You will not agree on the distance the light has traveled from the plane's tail to the nose. Since speed is the distance traveled divided by the time taken, you will not agree on the time interval between the emission and the reception of the light. The strange thing is that the two observers measure different times even though they are watching the *same physical process*.

Einstein’s work allowed us to see that time cannot be absolute as we once thought. In other words, it is not possible to assign every event a time with which every observer will agree. Instead, all observers have their own measures of time. For example, imagine a reference clock at rest at the center of the earth, another clock on the earth’s surface, and a third clock aboard a plan. The clock that moves in the direction of the earth’s rotation (eastward) is moving faster than the clock on the earth’s surface, and so it should run slower. Similarly, the clock aboard the plane flying westward, against the earth’s rotation, is moving slower than the surface clock, which means that clock should run faster than the clock on the surface. So technically, you could extend your life by constantly flying eastward around the world!

Einstein then developed a new theory of gravity, called general relativity. His theory is based on a revolutionary proposal that space-time is not flat, but is instead curved and distorted by the mass and energy in it. For instance, imagine you wanted to travel from New York to Madrid, two cities that are almost at the same latitude. If the earth were flat, the shortest route would be to head straight east. However, due to the earth's curvature, the path on a flat map looks curved and longer, but it is actually shorter. Instead of traveling 3,707 miles, you would get there in 3,605 miles by following the curve. In Einstein's theory, gravity is not like other forces; instead, it is a consequence of the fact that mass distorts space-time, creating curvature.

Scientists Are Still Searching for a Unified Theory but Agree that Our Existence Came From Pure Luck

While we have many theories to explain how gravity and quantum particles interact in the universe, these separate theories contradict one another. Quantum theory and general relativity don't necessarily work together. As a result, physicists are searching for a theory that will unify three out of the four fundamental forces of nature: weak nuclear force, strong nuclear force, electromagnetism, and, of course, gravity. After generations of failure, there is one theory that could be the unifying theory that Einstein was looking for.

M-Theory isn't just one theory but rather a whole family of different theories, each of which is a good description of observations. Think of M-theory as a map. As we know, we cannot see the entire earth's surface on a single map. Instead, the usual Mercator projection used for maps of the world makes areas appear larger and larger in the far north and south and doesn't cover the North and South Poles. Therefore, to map the entire earth, you would need to use a collection of maps, each of which covers a limited range. As the maps overlap with one another, the areas in which they overlap would show the same landscape. M-theory is similar.

According to M-theory, our universe is not the only one. Instead, M-theory predicts that many universes were created out of nothing, each one with many possible histories and many possible states in the future. Many of these states will be unlike the universe as we know it today, and only a few of these universes would allow humans like us to exist. In fact, the question of our existence has long been debated. Some believe that our creation begins with the Old Testament when God created Adam and Eve only six days into creation. Scientists, however, take a different view and believe that humans are a recent creation in a universe that is about 13.7 billion years old.

The first scientific evidence that our universe had a beginning came in the 1920s. Up until this point, most scientists believed in a static universe that had always existed. However, Edwin Hubble analyzed the spectrum of light emitted from space and determined that nearly all galaxies are moving away from us, and the farther they are, the faster they are moving. He also concluded that the universe is expanding. If this is true, this means that galaxies also have a past. A past in which they were likely much smaller.

Today, we know that our solar system is quite "lucky." You see, seasonal weather patterns are determined mainly by the tilt of the earth's axis. So during the winter in the Northern Hemisphere, the North Pole has tilted away from the sun; however, this has an insignificant effect on the temperature of the planet. Instead, the tilt plays a much larger role. Planets with a large orbital eccentricity, which is the varying distance from the sun, will see much more extreme temperatures. For example, Mercury has a 20 percent eccentricity, which results in the temperature being over 200 degrees Fahrenheit warmer at the planet's closest approach to the sun. If Earth's eccentricity was similar, our oceans would boil or freeze depending on the time of year! In other words, we are lucky that our planet has a small orbital eccentricity.

Our planet is under what scientists define as the *habitable zone,* in which temperatures of the planet are "just right." Therefore, according to Newton, our strangely habitable solar system didn't "arise out of chaos by the mere laws of nature." Instead, he believed the order of the universe was created by God. Many people still believe in this model; however, today's astronomers, physicists, and scientists argue that it wasn't divine intervention that brought our habitable planet into being; instead, it was a number of incredible factors that came together and supplied a conducive environment for our existence. In other words, we are lucky and fortunate to be alive!

Final Summary

The mysteries of our universe have long been explained away as an act of divine intervention. With gods of love, war, sun, stars, rain, and more, ancient societies explained the natural phenomena of the world through the pleasure or displeasure of various deities. However, since the discoveries made by the ancient Greeks, scientists and physicists have discovered the ins and outs of the mysterious world we live in. The universe is governed by physical laws, and those laws can tell us exactly how the universe behaves. However, many laws don’t work well together, so scientists are still searching for the unified theory that will unite these laws and become the theory of everything.