

The Elusive Theory of Everything

By Stephen Hawking, Leonard Mlodinow on October 1, 2010

Physicists have long sought to find one final theory that would unify all of physics. Instead they may have to settle for several



IN BRIEF

- Stephen Hawking's work on black holes and the origin of the universe is arguably the most concrete progress theoretical physicists have made toward reconciling Einstein's gravitation and quantum physics into one final theory of everything.
- Physicists have a favorite candidate for such a theory, string theory, but it comes in five different formulations, each covering a restricted range of situations.
- A network of mathematical connections, however, links the different string theories into one overarching system, enigmatically called M-theory: perhaps the network is itself the final theory.
- In a new book, *The Grand Design*, Hawking and Caltech physicist Leonard Mlodinow argue that the quest to discover a final theory may in fact never lead to a unique set of equations. Every scientific theory, they write, comes with its own model of reality, and it may not make sense to talk of what reality actually is. This essay is based on that book.

A few years ago the city council of Monza, Italy, barred pet owners from keeping goldfish in curved fishbowls. The sponsors of the measure explained that it is cruel to keep a fish in a bowl because the curved sides give the fish a distorted view of reality. Aside from the measure's significance to the poor goldfish, the story raises an interesting philosophical question: How do we know that the reality we perceive is true?

The goldfish is seeing a version of reality that is different from ours, but can we be sure it is any less real? For all we know, we, too, may spend our entire lives staring out at the world through a distorting lens.

In physics, the question is not academic. Indeed, physicists and cosmologists are finding themselves in a similar predicament to the goldfish's. For decades we have strived to come up with an ultimate theory of everything—one complete and consistent set of fundamental laws of nature that explain every aspect of reality. It now appears that this quest may yield not a single theory but a family of interconnected theories, each describing its own version of reality, as if it viewed the universe through its own fishbowl.

This notion may be difficult for many people, including some working scientists, to accept. Most people believe that there is an objective reality out there and that our senses and our science directly convey information about the material world. Classical science is based on the belief that an external world exists whose properties are definite and independent of the observer who perceives them. In philosophy, that belief is called realism.

Those who remember Timothy Leary and the 1960s, however, know of another possibility: one's concept of reality can depend on the mind of the perceiver. That viewpoint, with various subtle differences, goes by names such as antirealism, instrumentalism or idealism. According to those doctrines, the world we know is constructed by the human mind employing sensory data as its raw material and is shaped by the interpretive structure of our brains. This viewpoint may be hard to accept, but it is not difficult to understand. There is no way to remove the observer—us—from our perception of the world.

The way physics has been going, realism is becoming difficult to defend. In classical physics—the physics of Newton that so accurately describes our everyday experience—the interpretation of terms such as object and position is for the most part in harmony with our commonsense, “realistic” understanding of those concepts. As measuring devices, however, we are crude instruments. Physicists have found that everyday objects and the light we see them by are made from objects—such as electrons and photons—that we do not perceive directly. These objects are governed not by classical physics but by the laws of quantum theory.

The reality of quantum theory is a radical departure from that of classical physics. In the framework of quantum theory, particles have neither definite positions nor definite

velocities unless and until an observer measures those quantities. In some cases, individual objects do not even have an independent existence but rather exist only as part of an ensemble of many. Quantum physics also has important implications for our concept of the past. In classical physics, the past is assumed to exist as a definite series of events, but according to quantum physics, the past, like the future, is indefinite and exists only as a spectrum of possibilities. Even the universe as a whole has no single past or history. So quantum physics implies a different reality than that of classical physics—even though the latter is consistent with our intuition and still serves us well when we design things such as buildings and bridges.

These examples bring us to a conclusion that provides an important framework with which to interpret modern science. In our view, there is no picture- or theory-independent concept of reality. Instead we adopt a view that we 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. According to model-dependent realism, it is pointless to ask whether a model is real, only whether it agrees with observation. If two models agree with observation, neither one can be considered more real than the other. A person can use whichever model is more convenient in the situation under consideration.

Do Not Attempt to Adjust the Picture

The idea of alternative realities is a mainstay of today's popular culture. For example, in the science-fiction film *The Matrix* 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). How do we know we are not just computer-generated characters living in a Matrix-like world? 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 everyone in the world suddenly decided that chocolate was repulsive or that war was not an option, but that has never happened. If the aliens did enforce consistent laws, we would have no way to tell that another reality stood behind the simulated one. It is easy to call the world the aliens live in the “real” one and the computer-generated world a false one. But if—like us—the beings in the simulated world could not gaze into their universe from the outside, they would have no reason to doubt their own pictures of reality.

The goldfish are in a similar situation. Their view is not the same as ours from outside their curved bowl, but they could still formulate scientific laws governing the motion of the objects they observe on the outside. For instance, because light bends as it travels from air to water, 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. 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 the goldfish formulated such a theory, we would have to admit the goldfish's view as a valid picture of reality.

A famous real-world example of different pictures of reality is the contrast between Ptolemy's Earth-centered model of the cosmos and Copernicus's sun-centered model. Although it is not uncommon for people to say that Copernicus proved Ptolemy wrong, that is not true. As in the case of our view versus that of the goldfish, one can use either picture as a model of the universe, because we can explain our observations of the heavens by assuming either 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 that the equations of motion are much simpler in the frame of reference in which the sun is at rest.

Model-dependent realism applies not only to scientific models but also to the conscious and subconscious mental models we all create to interpret and understand the everyday world. For example, the human brain processes crude data from the optic nerve, combining input from both eyes, enhancing the resolution and filling in gaps such as the one in the retina's blind spot. Moreover, it creates the impression of three-dimensional space from the retina's two-dimensional data. When you see a chair, you have merely used the light scattered by the chair to build a mental image or model of the chair. 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 change the model so that they again see things the right way up—hopefully before they try to sit down.

Glimpses of the Deep Theory

In the quest to discover the ultimate laws of physics, no approach has raised higher hopes—or more controversy—than string theory. String theory was first proposed in the 1970s as an attempt to unify all the forces of nature into one coherent framework and, in particular, to bring the force of gravity into the domain of quantum physics. By the early 1990s, however, physicists discovered that string theory suffers from an awkward issue: there are five different string theories. For those advocating that string theory was the unique theory of everything, this was quite an embarrassment. In the mid-1990s researchers started discovering that these different theories—and yet another theory called supergravity—actually describe the same phenomena, giving them some hope that they would amount eventually to a unified theory. The theories are indeed related by what physicists call dualities, which are a kind of mathematical dictionaries for

translating concepts back and forth. But, alas, each theory is a good description of phenomena only under a certain range of conditions—for example, at low energies. None can describe every aspect of the universe.

String theorists are now convinced that the five different string theories are just different approximations to a more fundamental theory called M-theory. (No one seems to know what the “M” stands for. It may be “master,” “miracle” or “mystery,” or all three.) People are still trying to decipher the nature of M-theory, but it seems that the traditional expectation of a single theory of nature may be untenable and that to describe the universe we must employ different theories in different situations. Thus, M-theory is not a theory in the usual sense but a network of theories. It is a bit like a map. To faithfully represent the entire Earth on a flat surface, one has to use a collection of maps, each of which covers a limited region. The maps overlap one another, and where they do, they show the same landscape. Similarly, the different theories in the M-theory family may look very different, but they can all be regarded as versions of the same underlying theory, and they all predict the same phenomena where they overlap, but none works well in all situations.

Whenever we develop a model of the world and find it to be successful, we tend to attribute to the model the quality of reality or absolute truth. But M-theory, like the goldfish example, shows that the same physical situation can be modeled in different ways, each employing different fundamental elements and concepts. It might be that to describe the universe we have to employ different theories in different situations. Each theory may have its own version of reality, but according to model-dependent realism, that diversity is acceptable, and none of the versions can be said to be more real than any other. It is not the physicist’s traditional expectation for a theory of nature, nor does it correspond to our everyday idea of reality. But it might be the way of the universe. This article was originally published with the title "The Elusive Theory of Everything" in *Scientific American* 303, 4, (October 2010)

ABOUT THE AUTHOR(S) Stephen Hawking's work laid the foundation for the modern understanding of black holes and the origin of the universe, although, as he has pointed out, he is at least as famous for his appearances on *The Simpsons* and *Star Trek: The Next Generation*. From 1979 to last year, he was Lucasian Professor of Mathematics at the University of Cambridge, the post once held by Isaac Newton. His books include the classic *A Brief History of Time*, which has sold more than nine million copies. Leonard Mlodinow is a theoretical physicist at the California Institute of Technology. He has authored seven books—including *Euclid's Window: The Story of Geometry from Parallel Lines to Hyperspace* and *The Drunkard's Walk: How Randomness Rules Our Lives*—as well as scripts for *MacGyver* and *Star Trek: The Next Generation*.