The universe is a hologram and other mind-blowing theories in theoretical physics

March 6 2018, by Lawrence Goodman

What if there is a deeper reality out there?

What if our universe is an illusion?

What if we are living in a hologram?

Cue *Twilight Zone* music.

Or, alternatively, ask associate professor of physics Matthew Headrick about his research. Headrick works on one of the most cutting-edge theories in theoretical physics—the holographic principle. It holds that the universe is a three-dimensional image projected off a two-dimensional surface, much like a hologram emerges from a sheet of photographic film.

"In my view, the discovery of holographic entanglement and its generalizations has been one of the most exciting developments in theoretical physics in this century so far," Headrick said. "What other new concepts are waiting to be discovered, and what other unexpected connections? We can't wait to find out."

Since 2016, Headrick has served as deputy director of the "It from Qubit: Quantum Fields, Gravity and Information" project, an international effort by 18 scientists and their labs to determine whether the holographic principle is correct. It is funded by a 4-year, $10-million grant from the New York-based Simons Foundation.

If Headrick and his colleagues can prove the holographic principle, they will have taken a major step toward achieving the holy grail in theoretical physics, a grand unified theory that can explain all the laws and principles governing reality. "We're not there yet," Headrick said, "but we're making progress."

Let's break down the holographic principle step-by-step:

Information

We'll start small, very small. It's long been thought that the universe at its most fundamental level is made up of subatomic particles like electrons or quarks. But now physicists believe those particles are made up of something even smaller—information.

When physicists talk about information, they mean the data that describe physical phenomena. The mass of an object, the direction of the spin of an electron, and e=mc^2 are all units of information.

If you gathered all the information that's out there, you would have the complete instruction booklet for building everything in our universe.

Qubits

The tiniest levels of the universe are governed by the laws of quantum mechanics. Here things start to get very weird and counterintuitive.

Units of information in the realm of quantum mechanics are called qubits.

Headrick studies the quantum entanglement of qubits, a very strange phenomenon unique to the realm of quantum mechanics.

Suppose you have two qubits whose values can be either 1 or 0. When the qubits are entangled, their values become correlated. When you measure the first qubit, its value might turn out to be 0. Check the other qubit, its value might be 0, too. But what if the first qubit has a value of 1? The second qubit's value could also change to 1.

It's as if the qubits communicate with each other, with the first telling the second, "Hey, this physicist over here just found out I'm a 1. You better be a 1, too." Amazingly and bizarrely, this communication can happen over vast distances with messages seemingly relayed faster than the speed of light.

Qubits are flat

In most cases, when you drop an object into a jar—we'll use a jelly bean—it will fall inside and take up space. Put in another jelly bean, the amount of unfilled space shrinks and the volume of the jelly beans increases.

It doesn't work this way with qubits. Qubits won't fall into the jar but instead spread out on a surface. Add a qubit, it will adhere to the side of the jar. Add another qubit, it will do the same. Increasing the number of qubits doesn't increase the volume. Instead, it increases the surface area the qubits take up.

More and more qubits spreading out across a flat surface—this is how you get the two-dimensional plane described by the holographic principle.

So how do you get three dimensions?

Once you move beyond the realm of the teeny-tiny, the laws of quantum mechanics no longer work. Strange as it sounds, on the macrocosmic level, you need a different set of laws of physics to explain what's going on.

Enter Einstein's theory of relativity. To calculate cosmic events like the path followed by light or the orbit of Mercury around the sun, you need the theory of relativity.

The building blocks of relativity are also units of information. Now though, they're called bits.

And bits behave in a way that's much more familiar to us. They exist in three dimensions.

So how do you get a hologram?

Let's go back to that two-dimensional surface covered with entangled qubits. Since the value of a qubit changes depending on the value of its entangled pair, there's a degree of indeterminacy built into the system. If you haven't yet measured the first qubit, you can't be sure about the second. The amount of uncertainty in any given system is called its entropy.

As qubits become entangled and disentangled, the level of entropy rises and falls. You wind up with fields of entropy in a constantly changing state.

The holographic principle holds that our three-dimensional world is a representation or projection of all this activity taking place on a two-dimensional surface full of qubits.

Putting it all together

It's always bothered physicists that there is one set of rules for the microcosmic, quantum mechanics, and another for the macrocosmic, the theory of relativity. It doesn't make sense that there should be two different and incompatible groups of mathematical formulas at work in our universe. Physicists assume there must be some way to bring them into harmony.

So therein lies the central question for Headrick and his colleagues: Starting in the two-dimensional realm of qubits and quantum mechanics and then scaling up in size, how precisely do we wind up with bits and relativity? It's a matter of constructing a single mathematical model that explains the transformation.

Figure it out and you'll have solved one of the biggest mysteries in theoretical physics. From the tiniest to the largest phenomenon, we'll have a unified theory of reality.

Right now the holographic principle remains an unproven theory. Where it will lead next is an open question. Odds are though, it'll be stranger than anything yet imagined in science fiction.

Provided by Brandeis University

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