How to think about a four-dimensional universe

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Hubble image of SDSSJ0146-0929, a galaxy cluster that is massive enough to severely distort the spacetime around it. There's the mass of the visible stars and gas, but there's also a hidden amount of dark matter that adds to the cluster's mass. Credit: ESA/Hubble & NASA; Acknowledgment: Judy Schmidt

In Einstein's famous theory of relativity the concepts of immutable space and time aren't just put aside, they're explicitly and emphatically rejected. Space and time are now woven into a coexisting fabric. That is to say, we truly live in a four-dimensional universe. Space and time alone cease to exist; only the union of those dimensions remains.

This is what physicists give a single word: spacetime. Take four pens from your desk at work. Start with two and make a cross on your desk, so that they are sitting perpendicular two each other. Now add a third pen and position it so that it's perpendicular to both of the first two. To do this you can no longer let the pencils sit on the desk, which is a two-dimensional surface. You have to hold our contraption in the air, which is a part of the three-dimensional world that we're used to.

But we don't live in a merely three-dimensional world. Take your fourth pen and pierce it through the other three pens so that it's perfectly perpendicular to all of them. And no cheating, either: no angles less than 90 will do.

You can't. There are only three spatial dimensions. And beyond that, you can't even think of a fourth spatial dimension, because our brains evolved in a three-dimensional world (there are some people who claim that they can imagine a fourth dimension, but I suspect that they're either lying or just fooling themselves).

But while you can't hold in your mind the concept of a fourth dimension, you can experience it. The flow of time from past to future sits as its own dimension. You, holding your odd arrangement of pens, spans the dimension of time from the moment you first put it together until it all falls apart. For that duration, you created a four-dimensional piece of sculpture.

Physicists bind the three spatial dimensions and singular temporal dimension into the unified framework of spacetime. In the physics of Newton, that spacetime is the stage, and we—the objects and contents of the universe—are the actors. We hit our marks and say our lines, and the stage provides the background on which we perform our interactions. We know where the other actors are based on that same stage—they are on their marks saying their lines at the appointed cues.

But in general relativity, the stage itself becomes the starring actor, the name emblazoned on the Playbill. To make a theory of gravity compatible with the relativity of space and time (now spacetime), Einstein realized that gravity is not a force at all, at least not of the kind envisioned by Newton.

Spacetime is not a fixed stage, but a flexible membrane that suffuses the entirety of existence. It is a thing, an object and entity in its own right, a dynamical actor in the cast of characters in the universe. The universe consists of the usual assortment of particles and radiation and all their wonderful interactions, and those interactions don't happen on top of spacetime but along with spacetime, which has now joined their ranks.

Mass and energy (which do not need to be strictly separated, as they are now regarded as equivalent thanks to Einstein's special theory) change the shape of spacetime in their vicinity. You, reading this very text, are an entity in the universe, a thriving bundle of matter. You have mass and you have energy. The spacetime within you, throughout you, and near you is now distorted thanks to that mass and energy. Space and time are changed thanks to your existence.

And the rest of the universe responds. If we imagine an infinitely tiny particle traveling on a trajectory near you (in the parlance of physics we would call this a test mass to examine how gravity behaves absent other effects), we can ask how that particle responds to your presence. In the language of Newton we would say that your body exerts a gravitational field, an invisible influence, like the lingering smell of good cologne, and that the particle responds to that invisible influence by way of the sensation of a gravitational force, which changes its direction.

But in the language of Einstein there are no forces, no invisible strings. There is only spacetime and spacetime alone. In Einstein's radical reevaluation of gravity, all objects travel in straight lines, always and forever. But the spacetime that those objects must traverse bends beneath them. A hiker making their way from one waypoint to another may travel in a straight line—according to a map and according to their feet, which are always placed directly in front of one another with every step—but must follow the bends and curves (not to mention the gnarled tree roots) along the trail, lest they get lost in the wilderness.

And so objects—test masses, planets, beams of light—always travel in straight paths, but "straight" only in the sense that every step forward is always placed directly in front of the previous. The spacetime underneath and around those objects bends, and so too does the path the object takes.

This is gravity, according to Einstein. Mass and energy bend the shape of spacetime, and the bending of spacetime becomes an actor, affecting the paths and motions of everything else. With this awakening of gravitational insight, Einstein was able to successfully marry his concept of special relativity—that there are no fixed, universal standards of reference—with the gravitational force. In other words, not even spacetime itself is immune from the relativistic effects of differing viewpoints, and that mutation of spacetime gives rise to our experience of gravity.

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