My reading from Amanda Gefter, Trespassing on Einstein's lawn[1]

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Nothing and everything: the universe substance

How would we define nothing? I guess we would define it as the absence of something. The absence of everything.

How you can get something from nothing? It just seems impossible, but maybe we must be thinking about 'nothing' the wrong way. What if we had a state that was infinite, unbounded, and perfectly the same everywhere?

A 'thing' is defined by its boundaries. By what differentiates it from something else. That's why when you draw something it's enough to draw its outline. Its edges. The edges define the 'thing.' But if you have a completely homogeneous state with no edges, and it's infinite so there's nothing else to differentiate it from … it would contain no 'things.' It would be nothing.

Usually people think that to get to nothing, you have to remove everything. But if nothing is defined as an infinite, unbounded homogeneous state, you don't have to remove anything to get to it—you just have to put everything into a specific configuration.

If you blend up every object until everything in the universe looks exactly the same, and this completely undifferentiated stuff is spread out infinitely without bound. Everything will have disappeared into sameness. Everything becomes nothing. But in some sense it's still everything, because everything you started with is still in there.

Nothing is just everything in a different configuration. Let's call it H-state.

It's like if you build a sandcastle at the beach and then knock it down—where does the castle go? The castle's 'thingness' was defined by its form, by the boundaries that differentiated it from the rest of the beach. When you knock it down, the castle disappears back into the homogeneity of the beach. The castle and the beach, the something and the nothing, are just two different patterns.

How the universe began? Well, before the universe there was nothing. So to get a universe, nothing has to become something. They must be two different states of the same underlying thing—the same underlying reality—otherwise there'd be no way to transform one into the other. But how could nothing be a state of anything? Only now we realize that it's a state of infinite, unbounded homogeneity. If you start from that, the problem of the origin of the universe becomes thinkable, at least.

The nothing before the universe was a state of infinite, unbounded homogeneity, a featureless, uniform sameness that stretched on and on for eternity. Or at least until the universe was born. Which of course begged the million-dollar question: Why would the

[1] *Trespassing on Einstein's lawn: a father, a daughter, the meaning of nothing, and the beginning of everything* by Amanda Gefter, Batman Books, NY 2014.

nothing ever change? How could something defined by relentless sameness ever become different? Why would anything, like a universe, ever happen at all?

“It from bit” was Wheeler’s slogan for the idea that the physical universe is made not of matter but of information. In quantum theory, making an observation is equivalent to asking a yes-or-no question. Is the particle here or elsewhere? Is the cat dead or alive? Wheeler suggested that the very posing of the question creates a bit of information and that such bits were the fundamental building blocks of reality. “The universe and all that it contains (‘it’) may arise from the myriad yes-no choices of measurement (the ‘bits’),” Wheeler wrote. “Information may not be just what we learn about the world. It may be what makes the world.” It was a pretty weird idea, given our intuition that the fundamental building blocks of matter are just smaller pieces of matter, like particles.

Symmetry: on the origin of the universe

One way to get *symmetries to break* is to turn down the temperature. A puddle of water is highly symmetric—if you look at it from any angle and it looks the same. But cool it down enough and it freezes, forming ice crystals with more structure and less symmetry. Physicists, think about the universe the same way. In the heat of the big bang, the vacuum is symmetric. As the universe expands and cools, structure freezes in, like the twisted forms of virtual gluons. With structure comes mass. With mass comes everything else. The world we see around us and the people we see in mirrors are nothing more than broken shards of symmetry. Shards of nothing.

The most symmetric phase of the universe generally turns out to be unstable. One can speculate that the universe began in the most symmetric state possible and that in such a state no matter existed: the universe was a very empty vacuum, devoid both of particles and of background fields. A second state of lower energy is available, however, in which background fields permeate space. Eventually, a patch of the less symmetric phase will appear—arising, if for no other reason, as a quantum fluctuation—and, driven by the favorable energetic, start to grow. The energy released by the transition finds form in the creation of particles. This event might be identified with the big bang.… Our answer to Leibniz’s great question ‘Why is there something rather than nothing?’ then becomes ‘Nothing is unstable’.

The universe: did it once started?

The nothing could never change, because what would it be changing in reference to? You’d need some reference frame outside the nothing, which you can’t have, at least not according to the definition of nothing as infinite and unbounded. Nothing was a one-sided coin.

What we desperately needed was a story told from here inside the universe. Here inside the nothing. And if the universe is nothing, maybe the nothing never changes at all. Maybe the universe was never really born. *Maybe nothing just looks like something when you’re inside it*. If nothing was by definition unbounded then all you’d need to make it look like something was a boundary. Markopoulou had said that when you’re stuck inside the universe, you can’t see the whole thing, only the region within your light cone. Could a light cone provide the boundary you need to turn nothing into something?

Hermann Minkowski said, “Henceforth space by itself and time by itself are doomed to fade away into mere shadows and only a kind of union of the two will preserve an independent reality.” Space and time were shadows on the wall; spacetime was the cardboard.

Invariants: what’s invariant is what’s real.

Einstein was not so concerned with what was relative as with what was invariant, because he knew that *what’s invariant is what’s real.* In fact, he regretted having called his theory a theory of relativity, wishing instead that he had named it invariantentheorie: the theory of invariance.

Let’s say you have some kind of matter particle, like an electron. It’s described by a wavefunction, which has a phase. But the phase isn’t a physical thing. It’s just a measure of how far along the wave is in its cycle—whether it’s halfway up its peak or heading down its trough, or whatever—relative to some measuring apparatus. To some observer. If you’re watching a wave go by and you take a step to the left, you’ve now changed its phase, so obviously phase can’t be an intrinsic feature of the wave; it’s observer-dependent. Of course, phase differences mattered—that was the source of the interference pattern in the double-slit experiment. But phase in and of itself had no intrinsic meaning. The phase defines a reference frame.

Electromagnetism is a gauge force. Gauge is just another word for phase. It’s a point of view, a reference frame. Like Einstein’s principle of general covariance, the principle of gauge symmetry demands that all gauges are created equal; no reference frame is truer than the next. But local gauge shifts—shifts in points of view—leave a wavefunction with misaligned phases. To account for the mismatch and keep all reference frames on equal footing, you need a gauge force. The electromagnetic force ensures that we don’t confuse two different descriptions of one electron for two different electrons.

Gravity, electromagnetism, the nuclear forces … they’re all fictitious. They’re gauge-dependent, which is just another way of saying observer-dependent. They’re not invariant. But the fictitious force arises because you’re ‘really’ accelerating even though you don’t know it. Isn’t the point of relativity that you can’t say that you’re ‘really’ accelerating? You might be in an inertial frame with a force or you might be in an accelerating frame with no force, but they’re equivalent. You can’t privilege the sidewalk guy’s frame as the ‘real’ one—every observer’s view is equally valid.

Invariants: What’s real is what’s invariant

Einstein had said that Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of physical reality. “Real,” to Einstein, meant observer-independent, and the only way to figure out what was observer-independent was to compare all possible viewpoints and hope to find those rare keystones that don’t change from one to the next*. What’s real is what’s invariant.*

This is a philosophical truth that everybody already knows, at least instinctively. If we see something so strange that we can’t believe our eyes and we want to make sure that we haven’t lost our minds or been served a dosed cocktail, what do we do? We turn to the guy next to us and ask: Do you see that, too? If he says no, then we know that the thing's not invariant across reference frames, and that it's probably time to panic.

We must be careful to disentangle our stories about physics from its underlying mathematical structure, to not mistake different descriptions for different things. And now with invariance as our sole criterion for ultimate reality, we understand that the descriptions are what vary from one reference frame to the next—only structure has the potential to be invariant.

Particles: are they invariant? Are they real?

It was Wheeler who first realized that an antiparticle is just an ordinary particle for which time's arrow has been reversed. Antiparticles have to exist to account for the fact that, for some observers, a particle might look like it hitched a ride in a DeLorean.[2] Particles and antiparticles—they're not two different things. They're two different points of view.

Whenever I'd asked physicists to define a particle, they'd say it is *an "irreducible representation of the Poincaré symmetry group"*. The symmetry of spacetime defines everything in it. Poincaré symmetry is the symmetry of the flat, gravity-free spacetime of special relativity, the symmetry that enforces an equivalence between inertial frames that are rotated relative to one another or that are moving at different uniform velocities or whose origins are at different locations. What we call "particles" are the most basic invariant structures that, in flat spacetime, won't disappear in any frame.

We may fancy that symmetries don't break—they just appear broken when our reference frames are finite and the full symmetries of ultimate reality can't fit within our view. If you could see the whole of spacetime from some Archimedean point outside the universe symmetry would reign. Forces would disappear. And what would be left behind, invariant? Whatever it was was the ultimate reality.

Should we assume particles are real? Particles are excitations of fields (they're strings), so particles and fields really should go together. And the fields are defined in terms of the vacuum.

Supersymmetry shows that what looks like a boson in one frame looks like a fermion in another. In the higher-dimensional "superspace," bosons and fermions are identical. In ordinary space, they are different shadows of the same piece of cardboard, their distinction based only on the reference frame from which they're viewed.

Thanks to quantum uncertainty, pairs of virtual particles and antiparticles are constantly popping out of the vacuum. Fleeting ghosts, they surface for an instant, then meet and annihilate, disappearing back into the seething quantum sea. Should such a pair happen to emerge near a black hole, they can be divided by the horizon. Unable to partake in their mutual annihilation, the particle outside the horizon escapes into space while its antiparticle partner falls toward the singularity. Alone, separated from its partner, the escaped virtual particle becomes real. To an observer outside the black hole, it appears that the horizon is

[2] The DeLorean is a sports car manufactured by John DeLorean's DeLorean Motor Company for the American market in 1981–83. The car became iconic for its appearance as a modified time machine in the Back to the Future film trilogy.

radiating. Meanwhile, the negative energy of the antiparticle shrinks the black hole ever so slightly, so it loses mass and appears to slowly evaporate.

Particles, however, are really excitations of fields—quantum fields that, even in their lowest energy states, fluctuate around a mean value, the zero-point energy. A positive frequency fluctuation corresponds to the presence of a virtual particle, while a negative frequency fluctuation corresponds to a virtual antiparticle. But things get interesting when there's an event horizon.

In an infinite, unbounded space, frequencies of every possible wavelength are equally represented, so they cancel one another out, leaving behind what appears to be calm, empty space. But when you stick an event horizon into that space, everything changes. The vacuum is totally different depending on which side of the horizon you're on. The space outside the horizon is now finite and bounded. Its energy changes and, with it, everything else. New vacuum, new fields, new particles. Horizons create particles by restructuring the vacuum.

Particles can be observer-dependent. Particles aren't invariant. Particles aren't ultimately real.

Light, by definition, uses up its entire spacetime quotient on space, leaving none for time. In other words, it sees all of space in no time. From my point of view, the light leaving a star 5 million light-years away takes 5 million years to reach my eye. But from the light's point of view, its journey is instantaneous. From the light's point of view, the speed of light is not the speed of light. It has no speed. It is everywhere at once in a single instant. A photon doesn't see the universe. A photon sees a singularity. It sees the H-state.

Conclusion

Reality is radically observer-dependent. Every possible ingredient of ultimate reality has been crossed off. Nothing is invariant. Nothing is ultimately real.