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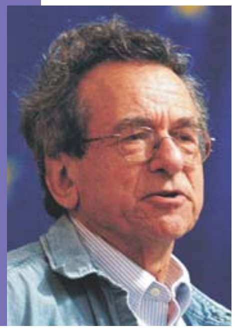

What's bad about this habit

N. David Mermin

N. David Mermin is a retired professor of physics in Ithaca, New York. He has many bad habits, but he does try to avoid reifying his successful abstractions.

After we came out of the church, we stood talking for some time together of Bishop Berkeley's ingenious sophistry to prove the nonexistence of matter, and that every thing in the universe is merely ideal. I observed that though we are satisfied his doctrine is not true, it is impossible to refute it. I never shall forget the alacrity with which Johnson answered, striking his foot with mighty force against a large stone, till he rebounded from it—"I refute it thus."

—James Boswell,
The Life of Samuel Johnson

There is nothing . . . more abstract than reality.

—Giorgio Morandi,
interview with Edouard Roditi

A bad habit is something you do, without being fully aware of it, that makes life harder than it needs to be. It is a bad habit of physicists to take their most successful abstractions to be real properties of our world. Since the distinction between real and abstract is notoriously problematic, you might wonder what it means to wrongly confer reality on something abstract. I shall illustrate our habit of inappropriately reifying our successful abstractions with several examples.

Perhaps the least controversial examples are provided by quantum mechanics. The quantum state may well be the most powerful abstraction we have ever found. ("Found" is a useful word here, since you can take it to mean "discovered" or "invented," depending on where you stand along the real–abstract axis.) Are quantum states real?

In considering what that question might mean, recall that in the early days Erwin Schrödinger thought that the quantum state of a particle—in the form of its wavefunction—was as real a field as a classical electromagnetic field is real. He abandoned that view when he recognized that nonspreading wavepackets were a peculiarity of the harmonic oscillator, and that the wavefunction of N particles is a field only in a $3N$-dimensional space.

But that does not prevent advocates of the de Broglie–Bohm "pilot wave" interpretation of quantum mechanics from taking the wavefunction of N particles to be a real field in $3N$-dimensional configuration space. They give that high-dimensional configuration space just as much physical reality as the rest of us ascribe to ordinary three-dimensional space. The reality of the wavefunction is manifest in its ability to control the motion of (real) particles, just as a classical electromagnetic field is able to control the motion of classical charged particles.

Why does reifying the quantum state make life harder than it needs to be? Taking pilot waves seriously can lead you to spend a lot of time calculating, plotting, and proving theorems about the trajectory a (reified) point in configuration space is pushed along by a (reified) wavefunction. The trajectories make no predictions that can't be arrived at using ordinary, trajectory-free quantum mechanics. Their primary purpose is to fortify the view that quantum states are real—a bad habit.

Even for people who don't believe in pilot waves pushing particles, reifying the quantum state can make life harder than it needs to be. It can make them worry about faster-than-light influences in the kinds of experiments first brought to attention by the famous Einstein-Podolsky-Rosen paper. In such experiments a system instantaneously acquires a state as a result of actions confined to the vicinity of a second faraway system that no longer interacts with the first. If the state of the first system is a real property of that system, then something real has clearly been transmitted to the first system from the distant neighborhood of the second at superluminal speed. If the state is merely a useful abstraction, then what, if anything, has been transmitted and where (or to whom) is far more obscure.

Reifying the quantum state also induces people to write books and organize conferences about "the quantum measurement problem" rather than acknowledging, with Werner Heisenberg, that "the discontinuous change in the [quantum state] takes place . . . because it is the discontinuous change in our knowledge . . . that has its image in the discontinuous change of the [state]."

Admittedly, you can't entirely eliminate the discomfort that gives rise to "quantum nonlocality" and "the measurement problem" by acknowledging that quantum states are not real properties of the systems they describe. But the recognition that quantum states are calculational devices and not real properties of a system forces one to formulate the sources of that discomfort in more nuanced, less sensational terms. Taking that view of quantum states can diminish the motivation for theoretical or experimental searches for a "mechanism" underlying "spooky actions at a distance" or the "collapse of the wavefunction"—searches that make life harder than it needs to be.

Quantum fields

Of course, ordinary nonrelativistic quantum mechanics is just a phenomenology—a simplified version of quantum field theory, the most fundamental theory we have about the constituents of the real world. But what is the ontological status of those quantum fields that quantum field theory describes? Does reality consist of a four-dimensional spacetime at every point of which there is a collection of operators on an infinite-dimensional Hilbert space?

When I was a graduate student learning quantum field theory, I had a friend who was enchanted by the revelation that quantum fields were the real stuff that makes up the world. He reified quantum fields. But I hope you will agree that *you* are not a continuous field of operators on an infinite-dimensional Hilbert space. Nor, for that matter, is the page you are reading or the chair you are sitting in. Quantum fields are useful mathematical tools. They enable us to calculate things.

What kinds of things? Trajectories in spark chambers, nuclear level diagrams, atomic spectra, tunneling rates in superconductors, for example. It's wonderful that the same tool—fields of operators on Hilbert space—works for all those different purposes, but one should not confuse the tool with the reality it helps to describe.

Where does the demotion of quantum fields from real things to calculational tools leave the reality of plain old *classical* electromagnetic fields, which represent the kind of reality that Schrödinger initially wanted his wavefunctions to have. When I was an undergraduate learning classical electromagnetism, I was enchanted by the revelation that electromagnetic fields were real. Far from being a clever calculational device for how some charged particles push around other charged particles, they were just as real as the particles themselves, most dramatically in the form of electromagnetic waves, which have energy and momentum of their own and can propagate long after the source that gave rise to them has vanished.

That lovely vision of the reality of the classical electromagnetic field ended when I learned as a graduate student that what Maxwell's equations actually describe are fields of operators on Hilbert space. Those operators are quantum fields, which most people agree are not real but merely spectacularly successful calculational devices. So real classical electromagnetic fields are nothing more (or less) than a simplification in a particular asymptotic regime (the classical limit) of a clever calculational device. In other words, classical electromagnetic fields are another clever calculational device.

Space and time

What that device enables us to calculate, of course, are classical spacetime trajectories. What about spacetime itself? Is that real? Spacetime is a (3+1)-dimensional mathematical continuum. Even if you are a mathematical Platonist, I would urge you to consider that this continuum is nothing more than an extremely effective way to represent relations between distinct events. And what is an event?

An event is a phenomenon that can usefully be represented as a mathematical point in spacetime. It is thus a phenomenon whose internal spatial and temporal extension *we* deem to be of no relevance to any of the questions that interest *us*. In introducing special relativity in 1905, Einstein, despite his later concerns about physical reality in the quantum theory, was well aware of the abstract character of events. Early in his paper he calls attention to "the inexactness which adheres to the concept of the simultaneity of events at (approximately) the same place, which," he notes, "must be bridged by an abstraction."

So spacetime is an abstract four-dimensional mathematical continuum of points that approximately represent phenomena whose spatial and temporal extension we find it useful or necessary to ignore. The device of spacetime has been so powerful that we often reify that abstract bookkeeping structure, saying that we inhabit a world that *is* such a four- (or, for some of us, ten-) dimensional continuum. The reification of abstract time and space is built into the very languages we speak, making it easy to miss the intellectual sleight of hand. Reifying (classical) electric and magnetic fields is a more recent bad habit, which also came to be taken for granted until it started to unravel with the arrival of quantum electrodynamics, which promoted (or, if you prefer, demoted) the fields to quantum fields—abstract calculational devices.

Why is it a bad habit to reify the spacetime continuum? Well, it can lead one to overlook the nature of some of those events that are abstracted into points. In 1905 Einstein also reminded us that when one says that the train arrives at 7 o'clock, what one means is that "the pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events." The event used to label the time is associated with the behavior of a macroscopic timekeeping instrument.

Macroscopic clocks have macroscopic spatial extent. Even the best clocks we have—atomic clocks—exploit a transition in a cesium atom, which is huge on the scale of an atomic nucleus, let alone on the scale of the Planck length. And even the size of an atom grossly underestimates the size of an atomic clock, for to make a clock out of cesium atoms you have to tune a cavity into resonance with the transition, which brings us back to the macroscopic level of Einstein's watch.

So when I hear that spacetime becomes a foam at the Planck scale, I don't reach for my gun. (I haven't any.) But I do wonder what that foam has to do with the macroscopic events that spacetime was constructed to represent and the macroscopic means we use to locate events.

Our own experience

Let me put it another way. The raw material of our experience consists of events. Events, by virtue of being directly accessible to our experience, have an unavoidably classical character. Space and time and spacetime are not properties of the world we live in but concepts we have invented to help us organize classical events. Notions like dimension or interval, or curvature or geodesics, are properties not of the world we live in but of the abstract geometric constructions we have invented to help us organize events. As Einstein once again put it, "Space and time are modes by which we think, not conditions under which we live."

In some ways the point may also be easiest to see in quantum physics, where time and space refer ultimately to the time and place at which information is acquired or, if you prefer, at which a measurement is made.

So I'd say that Dr. Johnson had it right when he insisted that what impinges directly upon us is real. The reality of a sore toe is impossible to deny. But the other side of "I refute it thus" is to be suspicious of the reality of those abstractions that help us impose coherence on our immediate perceptions. I doubt that Johnson's valid affirmation of the reality of direct perceptions constituted a refutation of Bishop Berkeley's skepticism about the constructions we find to help us organize those perceptions.

In my youth I had little sympathy for Niels Bohr's philosophical pronouncements. In a review of Bohr's philosophical writings I said that "one wants to shake the author vigorously and demand that he explain himself further or at least try harder to paraphrase some of his earlier formulations." But in my declining years, I've come to realize that buried in those ponderous documents are some real gems: "In our description of nature the purpose is not to disclose the real essence of the phenomena but only to track down, so far as it is possible, relations between the manifold aspects of our experience," and "Physics is to be regarded not so much as the study of something a priori given, but rather as the development of methods for ordering and surveying human experience."

I'm suggesting that this characterization of physics by Bohr is as true of classical physics as it is of quantum physics. It's just that in classical physics we were able to persuade ourselves that the abstractions we developed to order and survey our experience were themselves a part of that experience. Quantum mechanics has brought home to us the necessity of separating that irreducibly real experience from the remarkable, beautiful, and highly abstract superstructure we have found to tie it all together. ■