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Happy New Year or is it?

THE TIME WE THOUGHT WE KNEW

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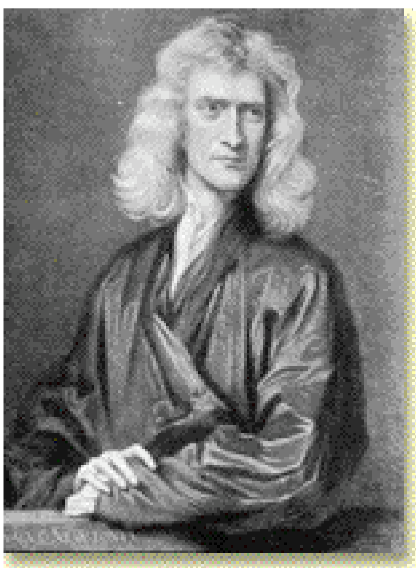
It was an unlikely place to be at 4:30 a.m., since I'm not much on celebrations and take minimal notice of most every holiday. Yet, a few years back, on a rainy Dec. 31 morning, I stood in Times Square, together with a handful of other early revelers, awaiting images on a giant screen of festivities on Kiribati, the first inhabited place on earth to welcome the new year. I was, as I recognized through the fog of exhaustion and the hazy steam billowing from manhole covers, re-enacting a struggle I'd been engaged in for decades.

Time dominates experience. We live by watch and calendar. We eagerly trade megahertz for gigahertz. We spend billions of dollars to conceal time's bodily influences. We uproariously celebrate particular moments in time even as we quietly despair of its passage.

But what is time? To paraphrase Justice Potter Stewart, we know it when we see it—but certainly, a few years into the 21st century, our understanding of time must be deeper than that. By now, you'd think, science must have figured out why time seems to flow, why it always goes in one direction and why we are uniformly drawn from one second to the next. The fact is, though, the explanations for these basic features of time remain controversial. And the more physicists have searched for definitive answers, the more our everyday conception of time appears illusory.



Sir Isaac Newton

According to Isaac Newton, writing in the late 17th century, "time flows equably without reference to anything external," meaning that the universe is equipped with a kind of built-in clock that ticks off seconds identically, regardless of location or epoch. This is the intuitive perspective on time, so it's no wonder that Newton's words held sway for more than 200 years.

In the early part of the twentieth century, however, Albert Einstein saw through nature's Newtonian facade and revealed that the passage of time depends on circumstance and environment. He showed that the wristwatches worn by two individuals moving relative to one another, or experiencing different gravitational fields, tick off time at different rates. The passage of time, according to Einstein, is in the eye of the beholder.

Numerous terrestrial experiments and astronomical observations leave no doubt that Einstein was right. Nevertheless, because the flexibility of time's passage becomes readily apparent only at high speeds (near the maximum possible speed, that of light) or in strong gravitational fields (near a black hole), nature lulls us into believing Newton's rigid conception. And so it's not surprising that nearly 100 years after Einstein's breakthroughs, it remains a great challenge, even for physicists, to internalize his discoveries fully.

But the cost of adhering to Newton's description of time is high. Like believing the earth flat or that man was created on the sixth day, our willingness to place unjustified faith in immediate perception or received wisdom leads us to an inaccurate and starkly limited vision of reality.

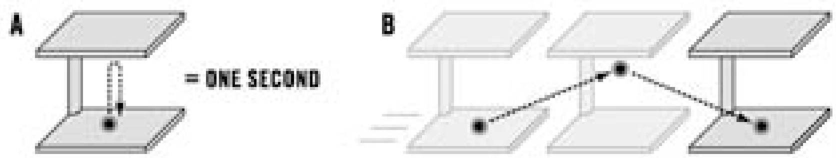
For one thing, relativity lays out a blueprint for time-travel to the future. Were you to board a spaceship, head out from earth at 99.999999 percent of light speed, travel for six months and then head back home at the same speed, your motion would slow your clock, relative to those that remain stationary on earth, so that you'd be one year older upon your return—while everyone on earth would have aged about 7,000 years. Or, were you to venture into space again and spend a year hovering a dozen feet above the edge of a black hole, whose mass was 1,000 times that of the sun, the strong gravitational field would slow your clock so much that on your return to earth, you'd find that more than a million years had elapsed.

To be sure, executing this strategy for catapulting yourself forward in time is beyond what we can now achieve, but scientists routinely use high-energy accelerators to propel particles, like electrons and protons, to nearly the speed of light, slowing their internal clocks and thereby sending them to the future. Though unfamiliar, forward time-travel is an unavoidable feature of relativistic reality.

Relativity also upends the way we traditionally organize reality. Most of us imagine that reality consists of everything that exists right now—everything that would be found, say, on a hypothetical freeze-frame image of the universe at this moment. The history of reality could thus be depicted by stacking one such freeze-frame image on top of the one that came before it, creating a cosmic version of an old-time flip-book. But this intuitive conception assumes a universal now, another stubborn remnant of Newton's absolutist thinking.

Let me explain. Clocks that are in relative motion or that are subject to different gravitational fields tick off time at different rates; the more these factors come into play, the further out of synchronization the clocks will fall. Individuals carrying such clocks will therefore not agree on what happens when, and so they will not agree on what belongs on a given page of the cosmic flip-book—even though each flip-book provides an equally valid compendium of history.

HOW DOES MOTION SLOW THE PASSAGE OF TIME?



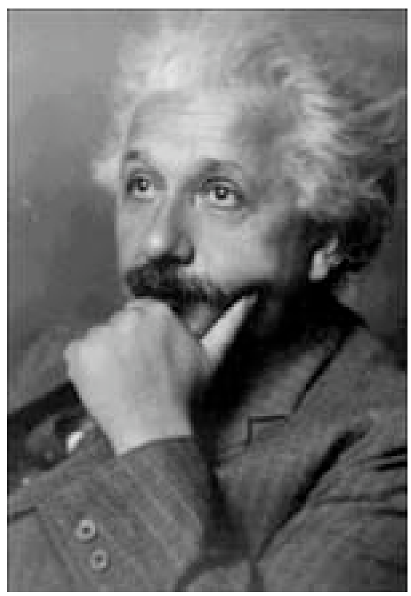
A hypothetical clock consists of two parallel mirrors with a photon (a ball of light) that bounces between them (A). If the mirrors are the right distance apart, the photon will complete the round-trip journey in one second. However, if the clock is moving (B), the photon travels on a diagonal path – a longer distance – and hence (since the speed of light is constant) takes longer to bounce between the mirrors. From our perspective, each second on the moving clock is thus longer than on the stationary clock.

Under these rules, what constitutes a moment in time is completely subjective. This is unfamiliar, and hence hard to accept, because we all experience the same gravitational field (the earth's), we all travel extremely slowly compared to light's speed (even the space shuttle never comes close to exceeding a ten-thousandth of light speed) and we all compare our conception of reality to beings who, by cosmic standards, are nearby. But by using our understanding to relax these measures, if only hypothetically, we learn that our experiences belie the truth.

For example, if you and I were sitting next to each other, our freeze-frame images of the present would be identical. But were you to start walking, the mathematics of relativity shows that the subsequent pages of your flip-book would rotate so that each one of your new pages would angle across many of mine; what you'd consider one moment in time—your new notion of the present—would include events I'd claim to have happened at different times, some earlier and some later.

As we pass each other in the street, this rotation is imperceptibly tiny; that's why common experience fails to reveal the discrepancy between our respective senses of past, present and future. But just as a tiny angular shift will cause a rocket to miss a distant target by a large margin, the tiny angular shift between our notions of now results in a significant time discrepancy if our separation in space is substantial. If instead of being next to me, you were 10 light years away (and moving at about 9.5 miles an hour), what you consider to have happened just now on earth would include events that I'd experienced about four seconds later or earlier (depending on whether your motion was toward or away from earth). If you were 10 billion light years away, the time discrepancy would jump to about 141 years.

In this latter case, your subsequent flip-book pages, your notion of the present—a notion that agreed with mine until you started walking—would include Abraham Lincoln on the day the Emancipation Proclamation took effect (if you walked away from me), or the victor of the hotly contested presidential election of 2144 preparing for his inaugural (if you walked toward me). That's not to say that you could save Lincoln's life or analyze mid-22nd century American presidential politics; at such enormous distances it takes signals, even traveling at light speed, a long time to make the trip. But the point is that even ordinary motion, when considered over vast distances, results in a marked change in our conception of reality, revealing how thoroughly subjective the temporal categories of past, present and future actually are.



In a very specific way, then, this realization shatters our comfortable sense that the past is gone, the future is yet to be and the present is what truly exists. Einstein was not hardened to the difficulty of absorbing such a profound change in perspective. Rudolf Carnap, the philosopher, recounts Einstein's telling him that "the experience of the now means something special for man, something essentially different from the past and the future, but this important difference does not and cannot occur within physics." And later, in a condolence letter to the widow of Michele Besso, his longtime friend and fellow physicist, Einstein wrote: "In quitting this strange world he has once again preceded me by just a little. That doesn't mean anything. For we convinced physicists the distinction between past, present, and future is only an illusion, however persistent."

Some physicists and historians see these as declarations laced with poignant hyperbole. Perhaps they are. It's hard to know whether Einstein was "convinced" to such a deep level that he had remolded his emotional sense of time to reflect his understanding of relativistic reality. But regardless of whether Einstein had succeeded, his remarks articulated the challenge—to allow carefully reasoned and experimentally verified investigations of the universe, however discomfiting their conclusions, to inform our lives with the same force as experience.

When quantum mechanics, the tremendously successful theory of atoms and subatomic particles, is taken into account, the challenge becomes greater still. Quantum mechanics has, at its core, the uncertainty principle, which establishes a limit on how precisely particular features of the microworld can be simultaneously measured. The more precise the measurement of one feature (a particle's position for example), the more wildly uncertain a complementary feature (its velocity) becomes. Quantum uncertainty thus ensures that the finer the examination of the microworld, the more frantically its physical features fluctuate, and the more turbulent it appears to be.

For subatomic particles, these fluctuations are well understood mathematically and have been precisely documented experimentally. But when it comes to time and space, the fluctuations speak to the very limits of these familiar concepts. On extremely short time intervals (about a tenth of a millionth of a trillionth of a trillionth of a trillionth of a second) and distance scales (about a billionth of a trillionth of a trillionth of a centimeter), quantum fluctuations so mangle space and time that the conventional ideas of left/right, backward/forward, up/down, and before/after become meaningless.

Scientists are still struggling to understand these implications, but many agree that just as the percentages in political polls are average, approximate measures that become meaningful only when a large respondent pool is canvassed, so conventional notions of time and space are also average, approximate concepts that become meaningful only when considered over sufficiently large scales. Whereas relativity established the subjectivity of time's passage, quantum mechanics challenges the conceptual primacy of time itself.

Today's scientists seeking to combine quantum mechanics with Einstein's theory of gravity (the general theory of relativity) are convinced that we are on the verge of another major upheaval, one that will pinpoint the more elemental concepts from which time and space emerge. Many believe this will involve a radically new formulation of natural law in which scientists will be compelled to trade the space-time matrix within which they have worked for centuries for a more basic “realm” that is itself devoid of time and space.

This is such a perplexing idea that grasping it poses a substantial challenge, even for leading researchers. Broadly speaking, scientists envision that there will be no mention of time and space in the basic equations of the sought-for framework. And yet—just as clear, liquid water emerges from particular combinations of an enormous number of H20 molecules—time and space as we know them would emerge from particular combinations of some more basic, though still unidentified, entities. Time and space themselves, though, would be rendered secondary, derivative features, that emerge only in suitable conditions (in the aftermath of the Big Bang, for example). As outrageous as it sounds, to many researchers, including me, such a departure of time and space from the ultimate laws of the universe seems inevitable.

A hundred years ago today, the discovery of special relativity was still 18 months away, and science still embraced the Newtonian description of time. Now, however, modern physics’ notion of time is clearly at odds with the one most of us have internalized. Einstein greeted the failure of science to confirm the familiar experience of time with “painful but inevitable resignation.” The developments since his era have only widened the disparity between common experience and scientific knowledge. Most physicists cope with this disparity by compartmentalizing: there’s time as understood scientifically, and then there’s time as experienced intuitively. For decades, I’ve struggled to bring my experience closer to my understanding. In my everyday routines, I delight in what I know is the individual’s power, however imperceptible, to affect time’s passage. In my mind’s eye, I often conjure a kaleidoscopic image of time in which, with every step, I further fracture Newton’s pristine and uniform conception. And in moments of loss I’ve taken comfort from the knowledge that all events exist eternally in the expanse of space and time, with the partition into past, present and future being a useful but subjective organization.

Yet my presence in Times Square that rainy morning—losing sleep to mark an arbitrary moment in the passage of what I truly believe to be a derivative concept—attests to the power of convention and experience. Regardless of our scientific insights, we will still mourn the evanescence of life and be able to thrill to the arrival of each newly delivered moment. The choice, however, of whether to be fully seduced by the face nature reveals directly to our senses, or to also recognize the reality that exists beyond perception, is ours.

Brian Greene, a professor of mathematics and physics at Columbia, is author of "The Elegant Universe" and the forthcoming "The Fabric of the Cosmos: Space, Time and the Texture of Reality."

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