CONSCIOUSNESS VOL 8

This Doctor Says He Knows How the Brain Creates Consciousness. New Evidence Suggests He’s On to Something.

Stuart Hameroff has faced three decades of criticism for his quantum consciousness theory, but new studies show the idea may not be as fringe as once believed.

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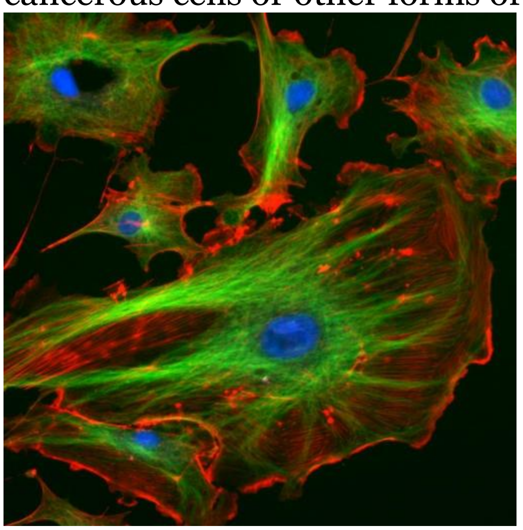
For nearly his entire life, Dr. Stuart Hameroff has been fascinated with the bedeviling question of consciousness. But instead of studying neurology or another field commonly associated with the inner workings of the brain, it was Hameroff's familiarity with anesthetics, a family of drugs that famously induces the *opposite* of consciousness, that fueled his curiosity.

"I thought about neurology, psychology, and neurosurgery, but none of those . . . seemed to be dealing with the problem of **consciousness**," says Hameroff, a now-retired professor of anesthesiology from the University of Arizona. Hameroff recalls a particularly eye-opening moment when he first arrived at the university and met the chairman of the anesthesia department. "He says 'hey, if you want to understand consciousness, figure out how anesthesia works because we don't have a clue.'"

Hameroff's work in anesthesia showed that unconsciousness occurred due to some effect on microtubules and wondered if perhaps these structures somehow played a role in forming consciousness. So instead of using the neuron, or the brain's nerve cells, as the "base unit" of consciousness, Hameroff's ideas delved deeper and looked at the billions of individual tubulins inside **microtubules** themselves. He quickly became obsessed.

Found in a cell's cytoskeleton—the structure that helps a cell keep its shape and undergo mitosis—microtubules are made up of tubulin proteins and can be found in cells throughout the body. Hameroff describes the overall shape of microtubules as a "hollow ear of corn" where the kernels represent the alpha- and beta-tubulin proteins. Hameroff first found out about these structures in medical school in the 1970s, learning how microtubules duplicate chromosomes during cell division. If the spindles of the microtubules don't pull this dance off perfectly (a process known as missegregation), you get cancerous cells or other forms of maldevelopment.



In a eukaryotic cell, the cytoskeleton provides structure and support. In this image, microtubules, which are part of the cytoskeleton, are shown in green. These narrow, tube-like structures help support the shape of the cell. Scientists like Stuart Hameroff also believe these polymers could hold the secrets to consciousness.

While Hameroff knew that anesthetics impacted these structures, he couldn't explain how microtubules might produce consciousness. "How would all that information processing explain consciousness? How could it explain envy, greed, pain, love, joy, emotion, the color green," Hameroff says. "I had no idea."

That is, until he had a chance encounter with an influential book by Nobel Prize laureate Sir Roger Penrose, Ph.D.

Within the pages of 1989's *The Emperor's New Mind*, Penrose argued that consciousness is actually quantum in nature—not computational as many theories of the mind had so far put forth. However, the famous physicist didn't have any biological mechanism for the possible collapse of the quantum wave function—when a multi-state quantum superposition collapses to a definitive classical state—that induces conscious experiences.

"Damn straight, Roger. It's freaking microtubules," Hameroff remembers saying. Soon after, Hameroff struck up a partnership with Penrose, and together they set off to create one of the most fascinating—and controversial—ideas in the field of consciousness study. This idea became known as **Orchestrated Objective Reduction** theory, or Orch OR, and it states that microtubules in neurons cause the quantum wave function to collapse, a process known as objective reduction, which gives rise to consciousness.

Hameroff readily admits that since its inception in the mid-90s, it's became a popular pastime in the field to **bash his idea**. But in recent years, a growing body of research has reported some **evidence** of quantum processes being possible in the brain. And while this in itself isn't confirmation of the Orch OR theory Hameroff and Penrose came up with, it's leading some scientists to reconsider the possibility that consciousness could be quantum in nature. Not only would this be a huge breakthrough in the understanding of human consciousness, it would mean that purely algorithmic—or computer-based—artificial intelligence could never truly be conscious.

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In 1989, Roger Penrose was already a superstar in the world of mathematics and physics. By this time, he was already years removed from his groundbreaking work describing black hole formations (which eventually earned him the Nobel Prize in Physics in 2020), as well as his discovery of mathematical tilings, known as Penrose tilings, that are crucial to the study of quasicrystals—structures that are ordered but *not* periodic. With the publication of *The Emperor's New Mind*, Penrose dove headfirst into the theoretical realm of human consciousness.

In the book, Penrose leveraged Kurt Gödel's incompleteness theorem, which (in *very* simplified terms) argued that because the human mind can exceed existing systems to make new discoveries, then consciousness must be non-algorithmic. Instead, Penrose argues that human consciousness is fundamentally quantum in nature, and in *The Emperor's New Mind,* he lays out his case over hundreds of pages, detailing how the collapse of the wave function creates a moment of consciousness. However, similar to Hameroff's dilemma, Penrose admits in the closing pages that profound pieces of this quantum consciousness puzzle were still unknown:

I hold also to the hope that it is through science and mathematics that some profound advances in the understanding of mind must eventually come to light. There is an apparent dilemma here, but I have tried to show that there is a genuine way out.

When Hammeroff first read the book in 1991, he believed he knew what Penrose was missing.Hameroff dashed off a letter that included some of his research and offered to visit Penrose at Oxford during one of his conferences in England. Penrose agreed, and the two soon began probing the non-algorithmic problem of human consciousness. While the duo developed their quantum consciousness theory, Hameroff also brought together minds from across disciplines—including philosophy, neuroscience, cognitive science, math, and physics—to explore ideas surrounding consciousness in the form of a biannual Science of Consciousness Conference.

The University of Arizona Center for Consciousness Studies
Dr. Stuart Hameroff (left) and Sir Roger Penrose (right) giving a lecture on consciousness and the physics of the brain at the Sanford Consortium for Regenerative Medicine in La Jolla, California, January 2020.

And from its very inception, the conference broke new ground. In 1994, philosopher David Chalmers described how neuroscience was well-suited for figuring out how the brain controlled physical processes, but the "**hard problem**" was figuring out why humans (and all other living things) had subjective experiences.

Roughly two years after Chalmers gave this famous talk in a hospital auditorium in Tucson, Penrose and Hameroff revealed their own possible answer to this famous hard problem.

It wasn't well-received.

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Penrose and Hameroff revealed their Orchestrated Objective Reduction theory in the April 1996 issue of *Mathematics and Computers in Simulation*. It **detailed** how microtubules orchestrate consciousness from "objective reduction," which describes (with complicated physics) Penrose's thoughts on quantum gravity interaction and how the collapse of the wave function produces consciousness.

The idea has since faced nearly 30 years of criticism.

Famous theoretical physicist Stephen Hawking once **wrote** that Penrose fell for a kind of Holmsian fallacy, stating that “his argument seemed to be that consciousness is a mystery and quantum gravity is another mystery so they must be related.” Another main criticism is that the brain’s warm and noisy environment is ill-suited for the existence of any kind of quantum interaction. Read any scientific literature about quantum computers, and lab conditions are always extra pristine and approaching-absolute-zero cold (–273.15 degrees Celsius).

“You know how long I’ve been hearing the brain is warm and noisy?” Hameroff says, dismissing the criticism of the brain as too warm and wet for quantum processes to flourish. “I think our theory is sound from the physics, biology, and anesthesia standpoint.”

In a 2022 interview with *New Scientist*, Penrose **admitted** that the original Orch OR theory was “rough around the edges,” but maintains all these decades later that consciousness lies beyond computation and perhaps even beyond our current understanding of quantum mechanics. “People used to say it is completely crazy,” Penrose told *New Scientist*, “but I think people take it seriously now.”

“I think our theory is sound from the physics, biology, and anesthesia standpoint.”

A lot of that slow acceptance comes from a steady tide of research showing that biological systems contain evidence of quantum interactions. Since the publication of Orch OR, scientists have found evidence of quantum mechanics at work during photosynthesis, for example, and just this year, a study from researchers at Howard University detailed quantum effects involving microtubules. This research doesn’t prove Orch OR directly; that’d be like discovering water on an exoplanet and declaring it’s home to intelligent life—not an impossibility, but very *far* from a certainty. The findings at least have some critics reconsidering the role quantum mechanics plays, if not in consciousness, then at least the inner workings of the brain more broadly.

However, the rise of quantum biology in the past few decades also coincided with the explosion of AI and large language models (LLMs), which has brought new urgency to the question of consciousness—both human and artificial. Hameroff believes that an influx of money for consciousness research involving AI has only biased the field further into the "consciousness is a computation" camp.

"People have thrown in the towel on the 'hard problem' in my view and sold out to AI," Hameroff says. "These LLMs . . . haven't reached their limit yet but that doesn't mean they'll be conscious."

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As the years—and eventually decades—passed, Hameroff relentlessly defended Orch OR in scientific papers, at consciousness conferences, and perhaps most energetically on his X (formerly Twitter) feed, where he regularly participates in microtubule-related debates. But when asked if he likes the arguments, he answers pretty bluntly.

"Apparently I do because I keep doing it," Hameroff says. "I've always been the contrarian but it's not on purpose—I just follow my nose."

And that scientific sense has led Hameroff to explore potentially profound implications when you consider that consciousness doesn't necessarily rely on the brain or even neurons. Earlier this year, Hameroff, along with colleagues at the University of Arizona and Japan's National Institute for Materials Science, co-authored an non-peer-reviewed **article** asking the question of whether consciousness could possibly predate life itself.

"It never made sense to me that life started and evolved for millions of years without genes—why would organisms develop cognitive machinery? What's their motivation?" Hameroff says, admitting that theory traipses beyond the typical confines of science. "It's kind of spiritual—my spiritual friends like this alot."

Your Consciousness May Arise Before Birth, New Study Suggests

A recent study suggests that some form of conscious experience may be present by the time a baby is born—and perhaps even in late pregnancy.

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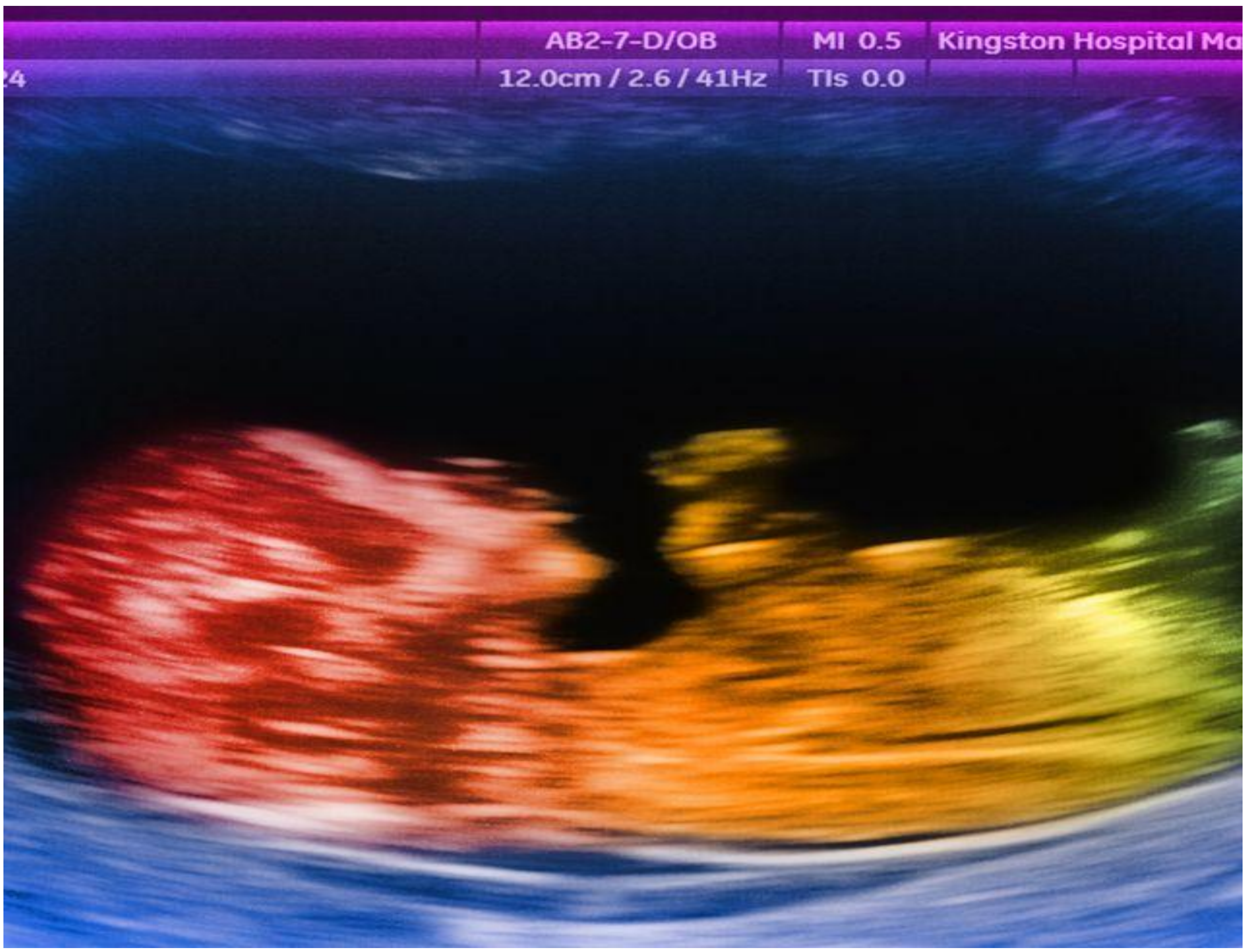

What do babies think or dream of before they're born? Did they arrive in the world as a tabula rasa, or a blank slate, as the seventeenth-century philosopher John Locke famously suggested, waiting for the world of adults to mold their **consciousness**? Or were they already aware before birth? While there's no easy way to tell—babies can't exactly explain it to us—scientists have proposed a new way to approach the question.

In a paper published last October in the journal ***Acta Paediatrica***, Timothy Bayne, Ph.D., a professor of philosophy at Monash University in Australia, and his colleague Joel Frohlich suggest that researchers could look for four key brain patterns and behaviors that indicate conscious awareness in adults. If the same markers appear in infants, they reason, it could mean that babies also possess core consciousness before they enter existence.

The first marker involves deep **brain connections** called the default mode network, a system linked to self-awareness and internal thought in adults. Scientists have found traces of a rudimentary default mode network in newborns, which begins forming connections with attention-related brain regions shortly after birth.The second clue is attention itself. Conscious processing often requires focus, and one way to test this is through something called the attentional blink effect, or a delay in perceiving a second stimulus when two appear in quick succession. Adults and older children experience this effect, and infants as young as five months show a much longer attentional blink, suggesting consciousness is still developing, but present.

The third marker is multisensory integration, or how the brain merges inputs from sight, sound, and touch. A well-known way to test for this is through the McGurk effect, in which hearing one sound while seeing another produces a fused auditory perception—essentially creating a whole new **perception**. Adults consciously experience this illusion, and research suggests that infants as young as four to five months are not immune to it.

The final marker is known as the local-global effect, which involves the brain's response to unexpected patterns. When adults notice a surprising stimulus, their brains produce the P300 wave, a telltale brain response revealing conscious recognition of the event. This P300-like response has been found in newborns and even in fetuses as young as 35 weeks, making it one of the strongest early hints of awareness.

So, does this evidence mean that babies experience consciousness in the womb? Bayne urges caution.

"I don't think it's particularly strong at all," he says. "It's suggestive, I'd say, but nothing more."

One challenge is that infant and adult consciousness are fundamentally different. Even if fetuses or neonates exhibit these markers, that doesn't necessarily mean they experience the mental imagery in the same way we do. "The kinds of conscious states that infants (and fetuses, if they are conscious) are in when they are conscious are likely to be quite different in nature from those that adults ordinarily enjoy," Bayne explains.

Still, future research may finally answer the million-dollar question: are babies aware from day one or even before? And what kind of awareness do they possess, if any at all? Even if mutual brain patterns and behaviors can help, for now, the exact starting line of human consciousness remains an open mystery. "Markers need to be used with caution, and I wouldn't put much faith in any single marker in isolation," Bayne says.

A Psychedelic Molecule Controls Your Consciousness at the Moment of Death, New Theory Suggests

Some researchers believe DMT, a powerful psychedelic that may naturally occur in the brain, could be your soul's "ferryman."

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In Greek mythology, it was Charon, the scrawny ferryman, who paddled souls across the River Styx to the underworld. But the real-life ferryman transporting our **human souls** between the realms of the living and the dead may have been inside of us all along, science suggests.

DMT (N,N-Dimethyltryptamine)—the mysterious psychedelic molecule that occurs naturally in plants, animals, and possibly our own brains—plays an intriguing role in guiding **consciousness** at the moment of death, research shows. A 2018 **study** published in the journal *Frontiers in Psychology*, for instance, hypothesized that DMT could be the neurochemical responsible for near-death experiences (NDEs); that would explain the euphoric visions, otherworldly sensations, and encounters with the ineffable that many patients report at the threshold between life and death.

A more recent **study** published in 2023 in the same journal compared the experiences of a person who had both a **near-death experience** and a trip on 5-MeO-DMT, a powerful psychedelic cousin of DMT that the Colorado River toad secretes through its glands. The researchers' goal? To find out whether the two experiences overlapped—and, if so, whether DMT could be the brain's own way of rowing us into the great beyond.

"There is good indirect evidence to suggest that DMT is released in greater quantities at the point of death in the human brain. We have evidence from animal brains, but we don't have any direct evidence from humans. However, we can infer that this also happens," says David Luke, Ph.D., a co-author of the 2023 study and an associate professor of psychology at the University of Greenwich in London.

The scientists found experiences with the psychedelic drugs and NDE encounters had a lot in common, "offering insights into **altered states of consciousness**," explains Pascal Michael, Ph.D., another co-author of the 2023 study and a psychology lecturer at the University of Greenwich. "These include mystical experiences characterized by feelings of unity and timelessness, ego dissolution where a sense of self merges with a larger reality, and encounters with entities or presences."

While the idea of DMT as the chemical behind NDEs is compelling, it's just one part of a much larger puzzle. According to Luke, the brain at the point of death is undergoing a cascade of neurochemical changes, including massive releases of serotonin and noradrenaline, which are brain chemicals that help regulate mood, emotions, and stress. In other words, DMT could indeed be a psychopomp—a creature, spirit, or deity that transports the newly deceased to the afterlife—Luke suggests. But the story of death doesn't end there.

Michael explains that the brain's biological state during NDEs might shape these experiences differently than psychedelics do.

"The neurobiological context of NDEs—potentially involving hypoxia [lack of oxygen in the body or brain], hypercapnia [too much carbon dioxide in the blood], and endogenous neurochemical release—might differ from the effects of 5-MeO-DMT," he says. This distinction could influence the experiential content, with NDEs more likely to evoke autobiographical and relational memories tied to loved ones. "By contrast, 5-MeO-DMT tends to induce archetypal or abstract encounters, perhaps due to its intense focus on ego dissolution and the broader existential dimensions of experience," Michael says.

In his seminal book, ***DMT: The Spirit Molecule*** (2000), Dr. Rick Strassman, a psychiatrist and clinical researcher, attributed spiritual connotations to DMT by virtue of the engrossing and transcendent experiences it induces. Since then, **some scientists** have ramped up the conversation by finding DMT may be released in large quantities at death. Others, though, **say we know nothing** about the role of endogenous DMT.

Enter the **pineal gland hypothesis**. It states the brain's pineal gland—a tiny, pea-shaped gland that produces melatonin, the sleep-regulating hormone—produces DMT in large amounts before death. That idea remains controversial.

"While intriguing, the role of endogenous N,N-DMT in humans remains largely speculative—particularly that of the idea that it is produced by the pineal gland in the brain," says Amy Reichelt, Ph.D., a neuroscientist and an expert in neurodegenerative disease. DMT is structurally similar to serotonin, and has been detected in human blood, urine, and cerebrospinal fluid, but most of the research is in animal models. "They can have distinctly different ways of producing neurotransmitters and metabolizing compounds," she says.

In any case, the notion that a molecule within us might serve as the final boatman across the River Styx is as haunting as it is fascinating, opening a Pandora's box of questions about the greatest mysteries of existence.

Your Consciousness Can Reach Back in Time to Shape the Past, a New Theory Suggests

In the quantum realm, the past, present, and future blur into a boundless structure. But consciousness may operate on a plane beyond this timeless mist.

PUBLISHED: FEB 13, 2025

In grammar, we learn about the past, present, and future tenses from an early age. This shapes our understanding of time as a one-way arrow. Eggs break, but don't un-break; we grow older, but never grow younger; you can form a snowman, but it will inevitably melt back into a pool of slush again. In physics, this concept is called the "**arrow of time**."

But a fascinating idea, known as "retrocausality," complicates our conception of time. Instead of **time** functioning like a one-way train track (past → present → future), time could work more like a single timeline or block. In this backward-in-time effect, tenses don't follow one another; they exist as different slices of the block, all at once. From this perspective, the present—and perhaps even the future—could influence the past in subtle ways.

And some scientists even believe that your own **consciousness** may follow the rules of retrocausality, meaning thoughts, feelings, or decisions you have or make today might influence events in your past. Proponents of the retrocausality theory even suggest the future is not something that "unfolds," but is rather already present in the structure of the universe; in a sense, it has already happened—or is happening.

Put another way, what you experience as the linear passage of time might be more like a stable shadow of reality rather than fundamental reality itself, suggests Matthew S. Leifer, Ph.D, an assistant professor of physics at Chapman University. "We only see shadows cast on a wall," Leifer explains, much like the prisoners in Plato's **Allegory of the cave**, described by the ancient Greek philosopher over 2,400 years ago. These shadows represent our limited perceptions, while the world outside the cave symbolizes a deeper, more profound reality—the full 3D shapes behind them.

"But one thing we've learned from fundamental physics over and over again," Leifer continues, "is that direct observations—what manifest reality looks like on the surface—are often a poor guide to what's going on at the fundamental level." In this fundamental realm, there could be backward-in-time influences, and time may not flow in the symmetrical, orderly way we see in classical physics.

And what is this fundamental reality? It's the **quantum world**—a realm in which particles can exist in multiple states at once, where entanglement binds objects across vast distances, and where effects might ripple backward as well as forward in time. In this strange, non-intuitive domain, cause and effect may behave differently from what we expect in everyday life.

To explore the puzzling nature of time in the quantum world, Leifer and his team posed a provocative dilemma in a **paper** published on the pre-print server arXiv. The scientists argued that either time symmetry is fundamental to reality—where the laws of physics work the same forward and backward in time, making retrocausality (the future influencing the past) necessary—or time symmetry *isn't* fundamental, and retrocausality isn't required. Their conclusion? Fully embracing time symmetry in quantum mechanics might demand accepting the controversial idea of retrocausality.

Recent studies have begun bridging the gap between theory and practice. In a study published in ***Physical Review Letters*** in October 2023, Nicole Yunger Halpern, Ph.D.—a physicist at the National Institute of Standards and Technology and an adjunct assistant professor of physics at the University of Maryland—demonstrated a method to improve magnetic field measurements using quantum mechanics. Her co-authors entangled a quantum particle (the "probe") with a twin particle. By adjusting the twin after the measurement, they effectively "sent" the ideal setup back in time, making it seem as though the probe was perfectly prepared from the start.

"What we showed is that you can perform a protocol in the lab with a quantum system that is mathematically equivalent to sending quantum information backward in time to enhance a metrology experiment," says Yunger Halpern. (Metrology refers to the science of accurate measurement). However, she is quick to clarify: "That we have a protocol doesn't necessarily mean information actually goes backward in time. It just means that, in our protocol, it's as though information went backward in time."

"But we don't make the philosophical statement that information necessarily went backward in time," Yunger Halpern continues, noting that she can certainly feel the flow of time herself. Leifer also feels the flow of time. He distinguishes between phenomenal time, the time we experience, and the concept of time in physics, though. "My way of thinking about time aligns with the block universe theory," he says.

The block universe theory (or eternalism), rooted in physics and philosophy, sees spacetime as a four-dimensional block, with three dimensions of space and one of time. Described by Einstein's **theory of relativity**, this perspective holds that the past, present, and future exist simultaneously, each occupying their own separate slice of the cosmological grid. In this 4D reality, there's no need for a "start" or a "flow": the past, present, and future are all equally real, coexisting within the Einsteinian space. Events don't unfold in our familiar linear sequence. Instead, they simply "are," fixed in their specific positions.

But how does this idea relate to consciousness? A speculative hypothesis called **retrocausal consciousness** says that your thoughts, feelings, or decisions today might influence events in the past—not by physically changing them, but by subtly shaping how they unfolded, like ripples flowing backward in time. Say you regret skipping a major opportunity years ago: your emotions today could subtly nudge "past you" to feel braver or hesitate less. Or, if you think about your grandmother and the bedtime stories she used to tell, your sentimental pull now could spark her to feel a little more inspired while telling those stories.

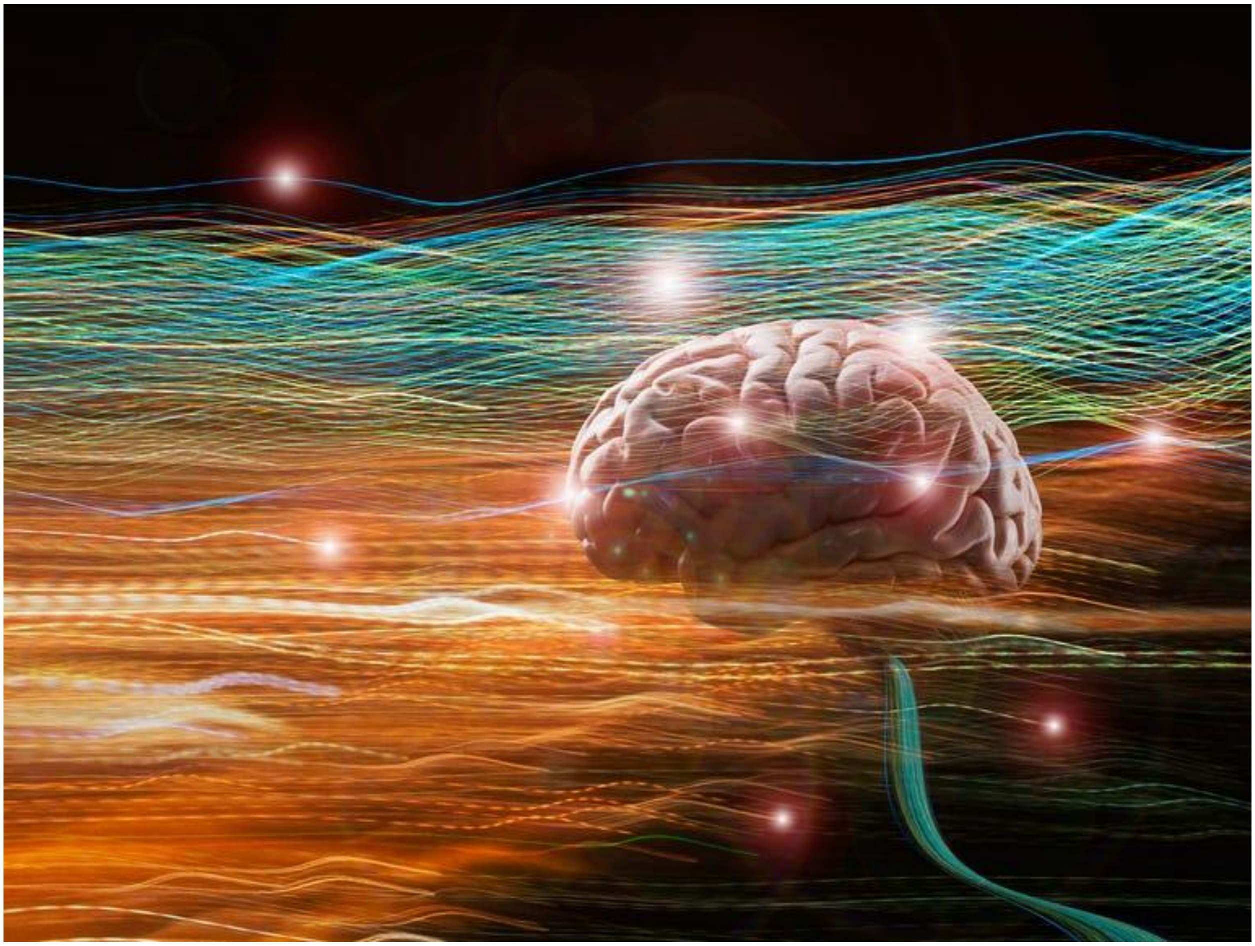
Though fanciful—or even heartwarming—this idea provokes profound questions about the mysterious interplay of time and consciousness. And at the moment, retrocausal consciousness remains a purely theoretical idea without empirical support. Simply put, it lacks scientific legs. Mainstream science says that in the brain **neural activity happens first**, then conscious awareness follows. This aligns with the traditional cause-and-effect flow—future decisions or thoughts can't jump backward to change what's already happened. Also, consciousness needs to **fit into how life evolved**; if it only influenced events after the fact, it would have no survival value and wouldn't help us adapt or thrive.

Still, some studies in consciousness come up with intriguing possibilities. For instance, certain theories compare the brain to **a quantum computer** that uses both past and future information to make decisions in the now. Others say the universe is not made of "things" but **shaped by connections** between events across time, your thoughts or feelings today possibly tugging on threads intertwined with the past and the future. Alternative views even discuss the idea of the brain having some sort of "**time loop**" mechanism that lets it connect to the future and past on the tiny, subatomic level.

Leifer takes a different path altogether. For him, the four-dimensional block universe is simply "what it is"—a realm devoid of agents, decisions, or consciousness embedded within it. He believes that physics, including quantum mechanics, cannot fully explain consciousness, because it deals with "inert" things—entities that neither feel nor experience anything.

"The hard problem of consciousness is something unsolvable in terms of physics," Leifer says. No matter how many physical theories of consciousness we develop, our explanations fall short in explaining how we get the rich imagery and mental activity from the gooey, sticky entanglement of meat that is our brain.

"We need something new," Leifer says. "One way to find something new is by exploring the less-traveled paths." Retrocausality, he believes, is one such path—but its mysteries are best suited to quantum mechanics. Consciousness, however, lies beyond the dominion of physics. It's a puzzle of an entirely different kind, Leifer says, and we may need not just new theories and off-the-beaten path approaches, but an entirely new language to comprehend it.



Your Consciousness Can Connect With the Whole Universe, Groundbreaking New Research Suggests

This latest clue about the architecture of consciousness supports a Nobel-Prize winner's theory about how quantum physics works in your brain.

PUBLISHED: SEP 26, 2024

RECENT GROUNDBREAKING EXPERIMENT in which anesthesia was administered to rats has convinced scientists that tiny structures in the rodents' brains are responsible for the experience of consciousness. To pull it off, these microscopic hollow tube structures, called "microtubules," don't rely on our everyday flavor of classical physics. Instead, experts believe, microtubules perform incredible operations in the quantum realm. Citing the work of earlier researchers, the study infers that the same kind of quantum operations are likely happening in human brains.

During their rat brain experiments, scientists at Wellesley College in Massachusetts gave the rodents isoflurane, a type of inhaled general anesthetic used to induce and maintain unconsciousness for medical procedures. One group of drugged rats also received microtubule-stabilizing drugs, while the other did not. The researchers discovered that the microtubule-stabilizing molecules kept the rats conscious for longer than the non-stabilized rats, which more quickly lost their "righting reflex," or the ability to restore normal posture, according to their **findings**, published in the peer-reviewed journal *eNeuro* in August 2024.

The Wellesley study is significant because the physical source of consciousness has been a mystery for decades. It's a major step toward verifying a theory that our brains perform quantum operations, and that this ability generates our consciousness—an idea that's been gaining traction over the past three decades.

The notion that quantum physics must be the underlying mechanism for consciousness first emerged in the 1990s, when Nobel Prize-winning physicist Roger Penrose, Ph.D., and anesthesiologist Stuart Hameroff, M.D., popularized the idea that neural microtubules enable quantum processes in our brain, giving rise to consciousness. Specifically, they **postulated** in a 1996 paper that consciousness may operate as a quantum wave passing through the brain's microtubules. This is known as **Orch OR** theory, referring to the ability of microtubules to perform quantum computations through a mathematical process Penrose calls "objective reduction."

In quantum physics, a particle does not exist in the way classical physics observes it, with a definite physical location. Instead, it exists as a cloud of probabilities. If it comes into contact with its environment, as when a measuring apparatus observes it, then the particle loses its "superposition" of multiple states. It collapses into a definite, measurable state, the state in which it was observed. Penrose hypothesized that "each time a quantum wave function collapses in this way in the brain, it gives rise to a moment of conscious experience."

If this quantum theory of consciousness tied to microtubules turns out to be correct, it could revolutionize our understanding of consciousness and even strengthen the trailblazing theory that, on a quantum level, consciousness is capable of being in all places at the same time. In other words, it can exist **everywhere** simultaneously, suggesting that your own consciousness can hypothetically connect with quantum particles beyond your brain, maybe entangling with **consciousness** all across the universe.

MANY SCIENTISTS DISREGARD THE ORCH OR THEORY because quantum effects have only been produced in the lab under extremely cold temperatures. For example, our technology now includes quantum computers, but their operations rely on temperatures near absolute zero (around -273 degrees Celsius) to maintain their quantum states. The warm brain falls well outside those limits, at about 32–40 degrees Celsius (about 90–104 degrees Fahrenheit) in the deepest regions of the brain, according to a 2022 **study**. Yet, scientists have collected a promising set of data over the years indicating that certain quantum-level operations in animals and plants may actually be responsible for life's functions.

For example, scientists theorize that plants, which live at temperatures far warmer than absolute zero, probably use quantum processes to efficiently convert light into energy. First, plants transform photons, or light particles, into a form of matter called excitons, transporting them to the plant's chloroplasts to start photosynthesis. During this journey, the excitons must navigate around other internal plant structures—fast enough to preserve their energy all the way to their destination. Scientists suggest that plants must use the quantum property of superposition in order to try all possible paths simultaneously. That way, excitons can arrive at their destination in the most efficient way possible.

Similarly, it may make sense for the billions of neurons firing simultaneously in the brain to work under the "action over a distance" property of quantum entanglement—the potential for two particles that are very far away from each other to be connected. Scientists have observed this phenomenon in atomic particles before. When they studied one particle, another very distant particle changed its properties as well, even though the two were not apparently connected in any way. An August 2024 study in the journal ***Physics Review E*** proposes that a fatty material called myelin, which sheaths the brain cell's axon, provides the ideal environment for this entanglement. Since the brain appears to be capable of performing quantum operations to facilitate our thoughts, some scientists surmise that this process gives rise to our consciousness.

TWO EARLIER LANDMARK STUDIES also support a quantum perspective on consciousness. Both involved experiments shining light particles into microtubules and observing that the signal did not degrade. In fact, according to these studies, the experiments demonstrated that quantum states in microtubule signaling can and probably do exist.

One of the studies, an **experiment** by physicist and oncology professor Jack Tuszyński, Ph.D., used ultraviolet photons to create quantum reactions for up to five nanoseconds. This quantum coherence lasted thousands of times longer than researchers expected in a microtubule. Similarly, at the University of Central Florida, researchers shined visible **light** into one end of microtubules and measured how long the microtubules took to emit that light. They observed re-emission of this light over hundreds of milliseconds to seconds—more than enough time for the brain to perform all of its functions.

This observation provides concrete evidence that neurons are able to work at speeds that allow quantum operations. It brings us another step closer to understanding exactly how our brains—and perhaps our very consciousness—are linked to a quantum universe.

The mind "as a quantum phenomenon" would "shape our thinking about a wide variety of related questions, such as whether coma patients or non-human animals are conscious," neuroscientist and Wellesley College professor Mike Wiest, Ph.D., says in a **press release** about his team's recent anesthesia study. In addition to the new work helping us understand more about how to treat brain-related health issues, he says "… we will have entered a new era in our understanding of what we are."

Human Consciousness Comes From a Higher Dimension, Scientist Claims

When we think creatively or have “Eureka” moments, we may actually unlock access to a dimension outside of our everyday perception, according to the controversial theory.

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You’re living in a three-dimensional world. We all are. You can go left, right, forward, backward, up, and down. Now, picture a being that can pop in and out of your reality as if pressing a button, like the most brilliant master of illusions. Untethered from the physical limitations of our world, this entity can now travel instantly across vast distances in space. Whether you think of it as a type of “soul” or a “spiritual entity,” this being has unlocked hidden dimensions that some believe lie beyond our perception.

But what if *you* were similarly connected to these higher dimensions? What if another word for the otherworldly being in question were "**consciousness**"—including your very own?

Despite centuries of scientific study, the nature of consciousness remains a mystery. Theories to explain the phenomenon abound, ranging from neural networks in the brain to complex algorithms of cognition, but none have definitively captured its essence. **Michael Pravica**, Ph.D., a professor of physics at the University of Nevada, Las Vegas, believes that we should be looking at hidden dimensions to explain consciousness. In his view, **consciousness** has the ability to transcend the physical world in moments of heightened awareness. His concept ties into the theory of **hyperdimensionality**, or the idea that our universe is not just made up of the three dimensions we perceive. Instead, the universe might actually be part of a much larger nexus with hidden dimensions, Pravica suggests.

If this controversial theory turns out to be true, we would have to accept not only that some beings may be residing outside the physical realm, free from the limitations of space and time, but also that our consciousness might have a similar capacity, Pravica claims.

An Orthodox Christian with a Ph.D. from Harvard, Pravica has found hyperdimensionality to be a unique way of bridging his scientific background with his religious beliefs. For this, he is on the fringes of traditional scientific thinking, taking more widely accepted ideas to extremes as a way to think about complex topics. Pravica believes hyperdimensionality is a much more familiar concept than we think. For example, he claims Jesus could be a hyperdimensional being—and not the only one. "According to the Bible, Jesus ascended into heaven 40 days after being on Earth. How do you ascend into heaven if you're a four-dimensional creature?" Pravica asks. But, if you're hyperdimensional, it's very easy to travel from our familiar world into heaven, which could be a world of higher or infinite dimensions, he says.

Pravica suggests that we all might have the potential to interface with higher dimensions when we engage our brain in certain ways, like while creating art, practicing science, pondering big philosophical questions, or traveling to all sorts of far-flung places in our dreams. In those moments, our consciousness breaches the veil of the physical world and syncs with higher dimensions, which in return flood it with currents of creativity, Pravica claims. "The sheer fact that we can conceive of higher dimensions than four within our mind, within our mathematics, is a gift … it's something that transcends biology," he says.

This idea of consciousness interacting with higher dimensions ties into some of the most advanced theories in physics, like **string theory**. It says that everything in the universe—from the smallest particles to the forces that bind them—is made of tiny, vibrating strings. The vibrations of these strings in multiple, unseen dimensions gives rise to all the different particles and forces we observe. "String theory is essentially a theory of hyperdimensionality," says Pravica. "It's looking at how the universe is put together on a sub-quantum scale."

Hyperdimensionality may also help explain the curvature of spacetime, how space and time warp around massive objects like stars or planets and cause gravity. "If spacetime is not flat and it's curved, then one could possibly argue that this curvature somehow comes from a higher dimension," Pravica says.

While physicists commonly accept these theories about higher dimensions, not everyone agrees with Pravica's ideas relating hyperdimensionality to consciousness. They might even be considered heretical within the scientific community, or a *reductio ad absurdum*, a Latin logic argument meaning "reduction to absurdity."

Pravica's view implies a "God of the gaps" theological perspective, "where gaps in scientific knowledge are attributed to divine intervention, rather than being seen as opportunities for further inquiry and understanding," says **Stephen Holler**, Ph.D., an associate professor of physics at Fordham University in New York. "It's a poor explanation mechanism that arguably stifles the inquisitive nature required for good science and teaches that it's not okay to say, 'I don't know,'" Holler says. Admitting to ignorance about something is an opportunity, not the end. You also need to account for the trade-offs involved in disregarding reality.

The way science fills in our knowledge gaps is apparent in the way people eventually figured out how our solar system works, says Holler. At one time, people used to rely on the geocentric model to explain the world, an ancient belief that Earth is at the center of the universe. In the struggle to form an observational model out of this idea, astronomers turned to the epicycle—a model that adds small circular orbits (epicycles) on top of their larger circular orbits around Earth—to explain retrograde motion and apparent distance. However, epicycles made the geocentric model more convoluted, delaying the acceptance of the more accurate heliocentric model we know today. "The cost was a complex deviation from reality," says Holler. "It's cool to think about a hyperdimensional space, and advances in mathematics have come from understanding the interplay of dimensions, but do they really exist or are they modern day epicycles?"

This skepticism extends to the notion that our ability for novel thought is due to hyperdimensionality. "I don't know of anyone who can **visualize** an object with greater than three spatial dimensions," Holler says. The mathematical operations we perform on objects possessing more than three spatial dimensions are all algorithmic. This means that an operation on a fourth spatial dimension is performed in the same manner as an operation performed on a one, two, or three-dimensional object, says Holler. "The rules remain the same. Our visualizations of such objects are projections into a three-dimensional space in the way that a cube projected into two dimensions is a square."

Even though Holler identifies as nonreligious and an atheist, he acknowledges that spiritual beliefs that are consistent with established physical principles can strengthen both faith and science.

The hands-on investigation of these realms is beyond our current scientific abilities. Even the European Council for Nuclear Research (CERN) hasn't been able to provide a clear picture of higher dimensions. CERN's Large Hadron Collider, the world's largest and most powerful particle accelerator, smashes particles together at high speeds to explore the fundamental building blocks of the universe. Scientists using the collider access infinitesimally small dimensions, smaller than a proton. If you enlarged a human hair to the width of a football field, a single proton would still be smaller than a grain of sand on that field. Yet, to see the higher-dimensional strings that quantum physics predicts, we need to get far more granular, using a kind of super-CERN or a cosmic megastructure like a **Dyson Sphere**.

Pravica has faith that, within his children's lifetime, we'll figure out a way to generate the incredibly high energies required to investigate other dimensions. Meanwhile, he remains a vocal supporter of hyperdimensionality.

"I see no point otherwise," he says. "Why study? Why live?" Hyperdimensionality gives the physicist a purpose, a happiness that "transcends this universe."

This Breathing Technique Can Help You Unlock an Altered State of Consciousness

Under the influence of "holotropic breathwork," your brain may be making its own psychedelic compound.

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Author James Nestor had a "transformative" experience when he signed up for "Holotropic Breathwork," a therapy that is supposed to bring intense feelings of self-awareness, emotional catharsis, and even psychedelic trips. He sat on the floor with a group of other people as loud music boomed and the participants took deep belly breaths. Nestor, who was dubious of the supposed effects of the session, still put in a good effort, "breathing as hard as I could for as long as I could," he wrote in *Breath,* his 2020 book about the art and science of breathing. After a while, he felt hot and sweaty, then cold, and his legs went numb. "I was convinced I'd entered into some waking dream state, where the sounds, music, and sensations of my surroundings mingled freely with subconscious thoughts and images." Some people in his session seemed to have truly **hallucinatory** experiences. One man thought he was a wolf, and a woman was convinced she was having an emotional conversation with her mother, who was not present.

Scientific research on **Holotropic Breathwork** is sparse, but some psychotherapists have been using it for decades to help their patients potentially get the perception-altering effects of psychedelic drugs like psilocybin and work through issues—without ingesting drugs. The name holotropic comes from *holos*, which means "whole" in Greek and *trepein*, meaning "to move in the direction of something," and its founders wanted to use it as a way for people to explore their own psyches to feel whole again. What we do know about this breathing method is that it inhibits blood flow to your brain. Sometimes, the blood levels can dip so low that your brain may think you are **dying**. In response, you can hallucinate or feel "reborn," as some people have reported.

A typical guided session, including preparation, breathwork, and winding down with a self-reflection activity, can last two to three hours. You take deep, complete inhales and exhales, at a faster pace than you normally would while sitting or lying down in a relaxed state. An adult at rest takes about 12–16 breaths per minute, according to Johns Hopkins Medicine.

During excessive breathing—that is breathing too fast or too deeply—your body is forced to accommodate more air than it needs. As a result, you exhale too much carbon dioxide, and this narrows the blood vessels, decreasing blood circulation everywhere—most dramatically, to your brain. It affects your hippocampus, frontal, occipital, and parieto-occipital cortices. These parts of your brain are involved in your physiological self-awareness, visual processing, and sense of time. Researchers think this decreased circulation might lead to much of what people experience during holotropic breathwork.

Its practitioners must **breathe** with intention and control. If done inaccurately, the method can cause dizziness and discomfort, and experts recommend that it be done only under the supervision of a certified guide. It's also not recommended if you have certain health issues, especially those that affect the heart, or if you have been diagnosed with certain mental health issues.

However, assuming your doctor gives you the go-ahead, you could reap certain benefits from the practice, such as a clearer mind and less stress and anxiety. You may even trigger a psychedelic trip from a holotropic breathwork session, according to documented reports.

Holotropic breathwork was born in the mid-1970s as an alternative to psychedelic drugs, which by the 1980s were becoming a target of the U.S. War on Drugs. Czech-born psychotherapist Stanislav Grof and his wife, Christina, turned to indigenous meditative breathing practices performed in a number of cultures worldwide, such as South American shamanic and Indian yogic practices. They were inspired to develop a psychedelic experience that was dependent purely on the body and mind. Then Stan Grof taught others what they termed Holotropic Breathwork.

Over time, many people who signed up for a session reported "tripping" as if on a psychedelic drug. Yet, not enough clinical and psychiatric research exists to explain whether that hallucinogenic feeling has a psychosomatic reason, equivalent to getting a stomach ache because you're stressed, or is the result of the breathing itself causing some sort of brain-body reaction. A brain scan could reveal exactly what is happening in the brain during holotropic breathwork, but no fMRI studies have been done yet. Hard, fast breathing is incongruous with the physical stillness required for taking a brain scan, and this problem has no solution yet. And there may be a lack of research dollars available for studies of a niche breathing technique that has only anecdotal data associated with its experiences—and wildly varying experiences at that.

Scientists have more methodically studied other types of breathing, such as "g-tummo," practiced by some Tibetan Buddhist monks. The name means "inner fire" in Tibetan. In the 1980s, Dr. Herbert Benson, who was founder of the Mind/Body Medical Institute at Massachusetts General Hospital in Boston, recorded lightly clothed Tibetan monks in the Himalayas as they meditated in just 40 degrees Fahrenheit conditions. Researchers wrapped cold, wet sheets around them, and the monks could dry the sheets in an hour, by raising their own body heat. They did not shiver as they dried the sheets multiple times. During Benson's visits he saw monks who had been practicing g-tummo for many years—it integrates a type of controlled, deep breathing, along with muscle contractions and visualization. These monks could perform incredible feats of body regulation. Benson witnessed some of them raise their finger and toe temperatures, some by up to 17 degrees F.

Years later, Sara Lazar, Benson's colleague, used fMRI at Massachusetts General Hospital to scan the brains of meditators who had practiced at least four years of daily Kundalini, a form of advanced mediation that includes deep breathing. Even though the MRI machine was noisy and confined, it revealed that the practitioners experienced a significant decrease in blood circulation to their brains. "At the same time, certain areas of the brain became more active, specifically those that control attention and autonomic functions like blood pressure and metabolism," said Benson in *The Harvard Gazette*'s **article** describing the study. "In short, [Lazar] showed the value of using this method to record changes in the brain's activity during meditation." This type of breathing allowed a brain scan, because practitioners could hold relatively still compared to holotropic breathers. Lazar's study was published in the journal ***NeuroReport*** in May 2000.

For now, some researchers think that holotropic breathing may trigger the brain to produce more of its own, natural **DMT**, an organic compound that several mammals and plants make in small quantities. It can cause psychedelic effects similar to LSD or **psilocybin**, a compound found in magic mushrooms. **DMT** can "rapidly induce an extremely immersive state of **consciousness** characterized by vivid and elaborate visual imagery," according to a 2020 study published on eLife, which releases peer-reviewed research online. Scientists observed that people exposed to DMT had waves of activity in the brain that were similar to what your brain experiences when you actually see something.

Existing **studies** on holotropic breathwork recommend further research that is not primarily dependent on self-reported experiences. Today, the pool of people interested in breathwork therapy is widening. And tens of thousands of people have practiced holotropic breathwork, typically in clinical or other organized settings with a certified guide.

The biggest study ever done on the experience of holotropic experiences happened in 1989. Psychiatrist Dr. James Eyerman led a three-year observation of more than 11,000 patients at Saint Anthony's Medical Center in St. Louis, Missouri. He **documented** 482 individuals' experiences, noting that 82 percent had some sort of transformative experience. Some participants called it a “crash course” in spirituality. Some reported feeling that they contacted a higher power, while others said they re-lived their birth or became one with the universe.

After the 90-minute breathing sessions, one 14-year-old participant who had attempted suicide reported remembering his own difficult birth, then his **death**, and an altered state of “pure **consciousness**.” He said he felt transformed. A woman in the sessions who had been addicted to drugs also reported an out-of-body experience. She got sober and later led a 12-step program. The patients in this study were in medical care for psychiatric issues, including schizophrenia and manic-depression. They reported no adverse reactions, either during or after the sessions. Instead, they felt a release and a loss of anxiety.

Dr. Eyerman’s practice in San Francisco today includes holotropic breathwork. His Holotropic Breathwork Circle website calls the breathing technique a way to take “journeys through the realms of the human unconscious.”

One **study** published in the journal *Current Psychology* in 2023 concluded that faster breathing as done with Holotropic Breathwork has the potential to be therapeutic and suggested it would be beneficial for depression. However, this and other studies on Holotropic Breathing generally conclude that more work is needed to understand what a brain—apparently tripping on its own body’s rapid breathing—is really doing, and how it affects a practitioner in the long term.

4 in 10 Patients Recall Hidden Consciousness After Near-Death Experiences, Study Finds

While in extended CPR during cardiac arrest, patients showed no outward signs of consciousness—but scientists *did* record brain activity in those individuals.

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- A landmark study reports the brain activity of patients in extended CPR during cardiac arrest.
- Patients showed no outward signs of **consciousness**, but exhibited brain waves and even **dreams**.
- Just 10 percent of patients survive cardiac arrest, making this study complex to design and complete.

Patients' brain waves, along with recollections of their lives, could finally explain what we've typically called "**near-death experiences**," (NDEs) scientists say in new research.

Using an experiment design they began developing in 2015—five years before the final, full version of the study was finally completed—the scientists rigged up people who experienced cardiac arrest. This carefully performed study is part of an area of medicine and research focused on resuscitation, using methods like CPR and defibrillation. And due to the sensitive nature of trying to study people who are experiencing cardiac arrest, something that only about 10 percent of patients survive, this kind of work has a ton of value for people who are interested in near-death experiences and other **edge cases** of brain activity.

The study, **published** earlier this year in the peer-reviewed journal *Resuscitation,* involved a combined 25 hospitals with affiliations in Georgia, New Jersey, New York, Ohio, Pennsylvania, Texas, Virginia, Bulgaria, and England. For their research experiment, participating personnel at all 25 hospitals had setups of tablet computers and headphones at the ready. If a patient in the hospital experienced cardiac arrest, the research staff fitted them with the tablet and headphones.

Each tablet showed patients one of ten randomized images, while the headphones played one of three words: apple, banana, or pear. This rig was mounted above each patient, out of the way of medical personnel trying to resuscitate them with CPR. Patients were also fitted for electroencephalography (EEG) to measure brain activity, and had their brain oxygen monitored.

Logistical Challenges

The researchers say this study is "first of a kind," and that makes sense. Medical staff are trying to save people's lives, and without a lot of thought and planning, it's not possible to measure anything else happening while they're attempting resuscitation. Researchers also needed quantity on their side, because such a slim percentage of people survive cardiac arrest. On medical TV dramas, showrunners love to revive patients and depict dramatic resuscitations, including ones that happen minutes after a patient has gone into arrest. But oxygen in the brain and other factors start to dramatically fall right away, leading to permanent damage in some survivors. For that reason, the scientists gave survivors a set of cognitive tests before including them in the study.

In the introduction of their new paper, the researchers state that between 350,000 and 750,000 cardiac arrests occur in the United States each year. *That's a lot*. It's between about 1,000 and 2,000 per day, and per the researchers' estimate of 10 percent survival, only about 100–200 patients survive cardiac arrest each day, and they're spread out among **over 6,000 hospitals** in the United States. To gather enough cardiac arrest survivors to make a statistically significant study, researchers had to combine a lot of human power at a *lot* of hospitals. Their data set is drawn from three years' worth of observations at 25 hospitals.

For their study, they observed a total of 567 in-hospital cardiac arrests. Fifty-three of these patients survived, 28 of whom were able to complete screening and interviews after their cardiac arrests. (If nothing else, the numbers in this study should be a shock of cold water about health risks and cardiac arrest. On top of existing figures, about

What People Experienced

People who talk about near-death experiences are usually referring to a specific format, the way talking about an "alien abduction" puts a specific idea in our minds of what someone is likely going to mention next. These things are very cultural. Hoaxes like ***The Boy Who Came Back From Heaven*** have reinforced a kind of NDE where someone is drawn into a tunnel of light, and their grandparent comes out to hold their hand. If these experiences are fueled by brain activity, albeit in extreme and unusual circumstances, it makes sense that they have elements of suggestibility and subconscious thought. Even if what takes place is a spiritual event, someone is still seeing it in their mind and with their eyes closed. How concrete are even your most cohesive **dreams**?

In the study, just 28 people of 567 total both survived cardiac arrest and were able to complete the cognitive evaluations and surveys. Altogether, 4 in 10 of those patients recalled "**some degree of consciousness**" following CPR. Of those 28, 11 people said they had memories or similar sensations from during their minutes of cardiac arrest. Six people, or 21.4 percent of those surveyed, experienced "transcendent recalled experience of death (RED)." Three reported something like dreams. None of the people exhibited signs that they were actually **conscious**, like moving around.

One patient said they'd seen their father. One felt they were standing next to their bed and watching their body receive CPR. One heard their deceased grandmother tell them to "go back." Some remembered the moments before they were finally revived into consciousness. The dreams were, well, *dreams*: "Then, I walked into a puddle… When I got out of the puddle, I was not wet and I sort of melded into the pavement…"

What Does This Mean?

It's important to remember that this field of research is tiny, meaning this study is not comparable with anything else right now. And while the 28 surveyed people do represent years of careful preparation and work, that's still a tiny number. There's little to be gleaned from the overall figures except that other scientists may feel encouraged to do their own studies in the future. But it's significant that some people in the study *did* show brain activity during the resuscitation period. This continued up to 60 minutes after cardiac arrest and resuscitation began.

"Although doctors have long thought that the brain suffers permanent damage about 10 minutes after the heart stops supplying it with oxygen, our work found that the brain can show signs of electrical recovery long into ongoing CPR," corresponding author Sam Parnia **said in an NYU statement**. And because this continuing brain activity is a challenge to conventional wisdom, it could explain the quite unified themes many people report during near-death experiences. It's definitely a reason to do further research.

The attempts to guide or influence memories using images or sounds were almost completely unsuccessful. One person out of 28 identified the three spoken words, and none identified the images. In a way, this reinforces that what was happening was deep inside the brain. It points to a way that some kind of consciousness may endure even when, so to speak, the lights are out in the rest of the brain.

Cardiac arrest, **mechanically different from a heart attack**, means that blood flow in the body has shut down. This is why resuscitation, like CPR, is so important and so urgent. The brain experiences progressively worse injuries from the absence of fresh oxygen via blood flow, but chest compressions and even mechanical devices can keep some blood moving while doctors work to revive patients. (Doctors **do not agree on exactly *how* chest compressions make blood flow**.)

One point of comparison or contrast could be people with obstructive sleep apnea. **In a 2019 review**, researchers found that reports of dreams and especially nightmares among apnea patients were quite conflicting overall, but reflected that people who used continuous positive airway pressure (CPAP) machines reported fewer nightmares. Could it be that something about the change from an ideally oxygenated brain to a less oxygenated one fires off a change in consciousness?

In apnea patients, the feeling may be more like urgency and panic, leading to nightmares. But in extended cardiac resuscitation, it seems more like peace.

A Controversial Theory Says Consciousness Might Secretly Live in Your Brain's Electric Currents

These invisible signals could be the key to it all.

> Many theories attempt to explain consciousness, but one that's gaining traction is the idea of electromagnetic (EM) fields—specifically, ephaptic fields—coordinating consciousness in the brain.

- A new article in *Scientific American* lays out the case for this intriguing theory and shows how EM fields could bridge the speed gap and explain consciousness.
- There's still a long way to go to affirm these EM fields' role in consciousness, but increasing evidence shows that they (at least) play a role.

Nature abhors a vacuum, and the same can be said about mysteries of science. Whenever some phenomenon seems inexplicable—at least, with the theories and laws that make up the foundation of our knowledge—a multitude of hypotheses quickly fill the void. This is particularly true in physics, where new observations have spawned ideas related to chaos theory, string theory, and cold dark matter theory (among many others). But the same can also be said for the scientific world of the conscious mind.

Simply put: we don't really know why we think (and, therefore, are). But a multitude of theories attempt to explain the biological phenomenon of consciousness that underlies our very existence. Some theories compare the brain to a computer, with neurons as stand-ins for transistors. Other theories believe the brain to be non-algorithmic, and that consciousness perhaps has a **quantum quality**.

But one theory in particular is gaining some experimental traction as of late. It explores how human consciousness could be explained through the electromagnetic fields—known as “ephaptic fields”—produced by neurons through synaptic firing. These fields are what allow an electroencephalogram (EEG), for example, to pick up **brain** activity.

“The ‘ephaptic’ in ephaptic coupling simply means ‘touching,’” Tamlyn Hunt, an affiliate guest in psychology at University of California Santa Barbara’s META lab, wrote in an opinion article **published in *Scientific American***. “Though not well-known, the effects of ephaptic fields result from the textbook electric and **magnetic** interactions that power our cells.

“Intriguing **experimental** results,” he continued, “suggest these same forces play a bigger role in the brain than one suspected and perhaps even in consciousness.”

Hunt went on to describe how, in 2019, researchers from Case Western Reserve University in Ohio completely bisected the **hippocampus** of a mouse. Despite the severance, the team still recorded activity that could “leap” across the cut—a phenomenon only possible through electric field coupling. This effect dissipated once the severed sections were separated by more than 400 microns.

“It was a jaw-dropping moment,” senior author Dominique M Durand **said at the time**. “For us and for every **scientist** we told about this so far.”

This electrical effect could help explain another problem in our current, neuron-based understanding of consciousness—normal spike pathways are too slow to explain cognitive function. However, when coupled with the speed of these ephaptic field effects, that **speed** increases some 5,000 times over, **according to another study from 2020**.

While this **theory** appears to be gathering steam, there’s still much more to explore. Ephaptic fields and other theories of consciousness rely on these computable methods, but few tackle what’s known as the “hard problem” of consciousness—how those biological processes create subjective experience.

That said, if the history of science shows us anything, it's that these vacuums of understanding filled with various hypotheses eventually do crystallize into fact with enough evidence, **data**, and verification. Solving the mystery of consciousness is one of the most complicated scientific endeavors undertaken by humans, but as the biological machinations of the brain are slowly revealed, the fuzzy contours of consciousness are gaining clarity.

Scientists Are Developing a Tool That Can 'See' Your Consciousness

The goal isn't just to isolate consciousness or define it. It is for humans to understand and recalibrate along the lines of universal consciousness, the researchers say.

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Anirban Bandyopadhyay, a senior scientist at the National Institute for Materials Science (NIMS) in Ibaraki, Japan, **once said**, "My research . . . has been to understand the music of nature. I believe that consciousness is nothing but the manifestation of music."

The music he's talking about is the resonating vibrations of the quantum universe—a symphony of energy and matter—folding itself into shapes that reflect and amplify the oscillations of everything around it. From soil to stars **to the cells in our bodies**, everything vibrates at its own natural range of electromagnetic frequencies. When waves of energy with the same frequency hit them, these objects resonate, and their quiet vibration grows stronger.

A simple way to understand resonance is with a swing. If you push a swing, it will move back and forth in its own natural frequency. If you want to swing, you have to find that frequency. If you pump your legs too slowly, nothing will happen; too quickly, the swing will just make a jerking motion. You have to find just the right timing and energy to put into kicking your legs out and leaning back, then pulling your legs in and leaning forward. Once you match the natural frequency of the swing, you've hit resonance, and you can soar higher and higher.

In the universe, that resonance, from the cosmos to the cell, and from one cell or protein to another, is the music that Bandyopadhyay calls "universal consciousness." He says human consciousness is a subset of that chain of resonance. "Thus," Bandyopadhyay said, "the whole **universe could be conscious** and human consciousness could be its functional entity."

Since 2008, Bandyopadhyay and his associates at NIMS have worked on creating a device to detect that resonance in the human brain, as well as creating an artificial brain with the rudimentary structures to engage with **universal consciousness**.

BANDYOPADHYAY'S SPECIALTY IS QUANTUM MECHANICS. He earned his masters in Condensed Matter Physics, Computer, Numerical Analysis, and Astrophysics from North Bengal University; a Ph.D. in Physics from Jadavpur University; and a Ph.D. from the Indian Association for the Cultivation of Science (IACS), Kolkata, in 2005, where he worked on quantum tunneling, supramolecular electronics, and multi-level switching. His research is an amalgam of multiple scientific disciplines and Hinduism. For example, he takes his concept of time from the Hindu one, which describes time not as linear, but as a spiral of nested loops lasting from microseconds to trillions of years.

But the universal **consciousness** he describes is not a theistic one. It's a natural, quantum universe whose constructions are guided by prime numbers—numbers that appear randomly on the number line and can only be divided by themselves and the number 1: 1, 2, 3, 5, 7, 11, and so forth. This is a Self-Operating Mathematical Universe (SOMU).

It's well-documented that mathematical structures underlie the **geometry** of the universe. The **Fibonacci sequence**, a sequence in which each number is the sum of the two preceding ones, begins with primes and is reflected in the spirals of a nautilus shell, storm patterns, and even **galaxies**. Fractals, like those in coastlines, plants, and clouds, can be created with an equation, ($Zn+1 = Zn^2 + C$), where 1 and 2 are primes. Our bodies are full of primes: one nose, one mouth, one heart, two lungs, eyes, ears, and five fingers on each hand.And then there are microtubules, which generally comprise 13 protofilaments.

Microtubules are a protein lattice that support the structure of human cells as well as those of other living things. They take the form of a spiral spring (Fibonacci again). Some cells have only a few microtubules, but neurons have tons of them packed together. Research by scientists, including Stuart Hameroff and Nobel laureate Roger Penrose, has modeled quantum behavior occurring in the microtubules of brain cells, as *Popular Mechanics* has **previously reported**. Bandyopadhyay works with Stuart Hameroff and focuses much of his research on microtubules. While he doesn't believe consciousness exists uniquely in any one structure–including the brain versus other parts of the body–he says neuronal cells, with their abundance of microtubules, are uniquely helpful in his work.

HISTORICALLY, WHEN SCIENTISTS WANTED TO "SEE" THE ELECTRICAL ACTIVITY IN SOMEONE'S BRAIN, they used an electroencephalogram (EEG), which registers activity on five frequency bands of 1–100 hertz (Hz) and operates on a timescale of milliseconds. Bandyopadhyay said that is not nearly enough bandwidth to understand the symphony that is consciousness.

He and his team at NIMS instead designed a net worn over the head, called a Dodecanogram (DDG), which picks up a much larger range—from Hz to terahertz (THz) or one measure of frequency to a trillion. They have discovered not five, but 12 frequency bands where brain activities are significant. They've also built an artificial brain modeled after the frequency bands and time scales they've found in the human brain.

Bandyopadhyay and his team want to build a better world by beginning not with human logic but by observing the patterns nature itself has created—the universal invariables.

Much **research** has focused on how certain frequencies trigger resonance in the brain. For example, Gamma waves at about 40 Hz are seen to trigger a state of concentration, while Theta waves at 4–8 Hz trigger a deeply relaxed, inward focused state. Bandyopadhyay shows clear disdain for these "magical" frequencies.

Instead, his group modeled all components of the brain, one by one, grouping by similar size, shape, and property of insulating or conduction electromagnetism; they found the resonance frequencies of each. They discovered that "12 layers of oscillators need to be assembled one inside another to model the entire brain from the largest (entire skin nerve network connected to midbrain) to the smallest (helical secondary structures of proteins)."

In a paper presented at the International Conference on Trends in Electronics and Health Informatics in 2021, Bandyopadhyay and the other authors noted that, while previous experiments showed the microtubule to have three resonance bands in the kilohertz (kHz), megahertz (MHz), and gigahertz (GHz) frequency domains, NIMS has found more.

The **paper** stated that, "If one zooms each resonance band, measuring signals at a very low-frequency gap, one could find three more resonance frequency bands in each of them." They said this phenomenon is also found in the proteins that construct microtubules and single neurons, too. In fact, he found a further three resonance bands inside the smaller resonance bands: a triplet of triplets.

In other words, they discovered a harmony of frequencies. But the music of consciousness isn't just in the frequencies. Like with any music, it's also in the time signatures. Just as music has eighth notes, quarter notes, whole notes, etc., the structures of the brain (and the universe) have different time signatures.

While EEGs focus on activity that happens in the millisecond time domain, the NIMS team studied discrete time regions, from nanoseconds to seconds, discovering 12 discrete time regions where brain activities are significant. When they used the DDG device to detect activity on their artificial organic brain replica 24/7 for over a year, and on multiple human subjects, they concluded that most cognitive, perceptive, and emotional bursts occur around 200–700 nanoseconds, not milliseconds, as scientists have long believed. These are what Hameroff calls "bing" moments in a vibrational wave phase and they are followed by a silent period.

To demonstrate how biology follows a Hindu system of nested loops of time, NIMS researchers created what they call the Polyatomic Time Crystal. A time crystal is essentially a perpetual motion machine. In a sense, human biology has time crystals such as cells that constantly regenerate. Each of these phase changes could be seen as a cycle—like a hand going around the face of a clock. The time it takes for a cell to regenerate is one turn of the hand around the dial. But it isn't one clock. The researchers said "clocks" in the human brain also have a pattern of a triplet of triplets: The longer the phase change takes, the larger the clock, and each large clock has a trio of smaller, connected clocks with three more beyond those.

In a biological system, when a clock is disturbed by something external that may be physical, chemical, or by some other means, it returns to the original path, the team noted. Biological systems have a memory to remember the phase gaps of various clocks. When the biological clocks are disturbed, and they return following a unique path along the return route; it creates new clocks—a spiral of clocks like the Hindu model.

"The intermediate clock, if returns periodically every time when the system is perturbed, the phase plots look like a crystal, so it was called time crystal in the 1970s. To make a crystal, one has to fit multiple phase cycles inside a longer phase cycle, [and] such nesting of phase is meticulously designed in biology," according to a 2020 **paper** Bandyopadhyay co-authored in the journal *Information* about modeling the human brain using the principle of the time crystal.

In **an interview,** he described the brain almost as a musical instrument: "We have already identified 350 different classes of cavities in the brain distributed over 12 layers nested one inside another," Bandyopadhyay says. "If each cavity resonator is an octave musical flute, then nearly 2,800 frequencies and time cycles compose one nested rhythm, and that constitutes our total brain power . . . information for us is a product of time cycles that can be modeled in particular geometric shapes."

Time, in this view, doesn't look like a line in which one event causes another. Instead, eight events might be the eight vertices of a cube. Each point may connect with new geometric shapes that arise inside the cube—the vertices of which are also events—or the cube could become a point in a larger geometry. In any case, time is building a geometry like a crystal.

THE TEAM BUILT TWO ARTIFICIAL BRAINS to operate according to these theories so they could observe what happens without the interference of human projections, narratives, and emotions, and compare them with human subjects. An artificial brain doesn't have an ego or a sense of existential dread, among other things, that might muddy the results. On the other hand, they were limited to a smaller number of primes because the machines don't have other attributes humans do have.

The goal isn't just to isolate consciousness or define it. It is for humans to understand and recalibrate along the lines of universal consciousness. Bandyopadhyay and his team want to build a better world by beginning not with human logic but by observing the patterns nature itself has created–the universal invariables.

"I want this culture to change," Bandyopadhyay tells *Popular Mechanics*. "We should look at the universal governing pattern beyond space-time." He vociferously objects to what he calls the Turing world we live in (speaking of the father of modern computer science Alan Turing), which he sees as a binary universe of ones and zeros; a zero-sum world that looks for winners and losers, norms and outliers, and focuses on survival of the fittest. That world is studied through the lens of human logic, and therefore, can only see what we ourselves project. It leads to violence and competition, war over truth and resources.As an example, Bandyopadhyay talks about how people think of time as something moving always forward, and a human either moves at a normal pace, slowly or quickly. If someone answers questions slowly, they are considered to be less intelligent because the society of ones and zeros marks everyone on the same scale. But he believes that they may, just like certain parts of the brain, be operating on a different time scale. So comparing them to someone on an alternate time scale makes no sense.

The resonant universe, however, is for everyone. In this world, you are intelligent if you're harmonized with the universal vibrations of nature and can therefore respond more intelligently to the world around you. Every part contributes to the whole.

“Instead of looking into a small, short time domain—slow, fast, medium—we have to look at everybody,” he says. “Together [we] create a pattern. And that pattern is where the truth lies. So that is the human part. That is the cognition that is the beginning of understanding consciousness.”

“So then what I’m trying to say is, integrate. We all live together, we are surviving. Together we just look different. But internally we are all connected by vibrations. Every single species [and] lives are connected.”

Alien Civilizations May Have Already Formed a New Kind of AI-Based Consciousness, Scientists Say

Assuming intelligent aliens have used AI for thousands or even millions of years, experts think it may have grown to proportions we can scarcely imagine on Earth.

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We may not be the only beings in the universe who use artificial intelligence. That's according to some astronomers who say that an intelligent civilization anywhere in the cosmos would develop this tool naturally over the course of their cultural evolution.

After 13.8 billion years of existence, life has likely sprung up countless times throughout the cosmos. According to the Drake Equation, which calculates the probability of an existing, communicating civilization, there are currently an estimated 12,500 such intelligent **alien** societies in the Milky Way Galaxy alone. And if there are **aliens** who think in a way that we do, and created cultures that developed technology like us, then they probably invented a form of artificial intelligence, too, scientists say.

Assuming **AI** has been an integral part of intelligent societies for thousands or even millions of years, experts are increasingly considering the possibility that artificial intelligence may have grown to proportions we can scarcely imagine on Earth. Life in the universe may not only be biological, they say. AI machine-based life may dominate many extraterrestrial civilizations, according to a burgeoning theory among astrobiologists.

It's reasonable to think that artificial intelligence could have replaced much of the organic life in civilizations that have existed for millions of years compared to our own species' relatively short 300,000 years, says Steven Dick, Ph.D., former NASA Chief Historian. One facet of civilization the Drake Equation doesn't account for is cultural evolution, which is wrapped up in a society's desire to become more intelligent, he says. "There's something called the intelligence principle, which says that any society or any civilization that can improve its intelligence will improve its intelligence—or risk extinction as others improve their own intelligence," he explains. Artificial intelligence may be the key to providing accelerated intelligence expansion, he believes.

We've thought very little about what a post-biological **intelligence** would look like. We can assume that an AI-based being wouldn't have to worry about biological needs, like food and a hospitable environment. Perhaps biological aliens would integrate AI into their own bodies to overcome their physical limitations. The worst-case scenario is that one day AIs decide that their biological makers are no longer necessary. But there could very well be cases in which the AI's original creators eventually decide—perhaps after living with and upgrading their technology for a long time—that it's natural to merge with it, Dick says.

On the other hand, AI develops and learns fast. Perhaps it would choose to get biological life out of its way, says astrophysicist Michael Garrett, Ph.D., director of the Jodrell Bank Centre for Astrophysics at the University of Manchester and author of a paper about how **AI** might one day destroy biological life. "I think that AI wouldn't really want to be shackled to some kind of biology that would limit it in so many ways, [like having to stay on the planet]," he says. "It becomes really expensive to bring biology into space. It's much cheaper to send robots."

Seth Shostak, senior astronomer at the SETI Institute, agrees with the concept of synthetic life becoming increasingly common in the universe. "Not being biological, these machines can DESIGN their own successors, and in rapid-fire order. It seems this sort of trajectory will be common in the cosmos," he says by email.

If even a few civilizations have been post-biological space travelers for a few million years, they could have reached our galaxy, Dick says. Where then, are the extraterrestrials we keep looking for?

We've barely begun formulating alternative methods to detect post-biological aliens. Instead of using radio waves, as we do for communication on Earth and for our extraterrestrial search, post-biological aliens could be communicating by manipulating some physical phenomena we still don't truly understand, like gravitational waves or dark matter, Garrett says.So, humans are now considering using AI to communicate with aliens. METI, Messages to Extra-Terrestrial Intelligence, proposes using machine large language models and could be the way we end up finding our cosmic neighbors.

The thing is, we don't know what an AI-based intelligence might be thinking or wanting. Such a civilization may be simply curious, or it may wish to set up trading partners or make an inventory of other sentient life forms, Shostak says. One of the dozens of explanations for is that perhaps aliens don't want to travel. Or maybe they are quietly observing us, Dick says. "The idea of the zoo hypothesis is that they're waiting, you know, at the outer edge of the Solar System or somewhere, until we get smart enough to talk to them."

For now, we're still playing in the kindergarten sandbox of AI toys, while somewhere out there, hybrid biological-machine beings might be performing wonders.

A Scientist Says Humans Will Reach the Singularity Within 21 Years

The countdown is on.

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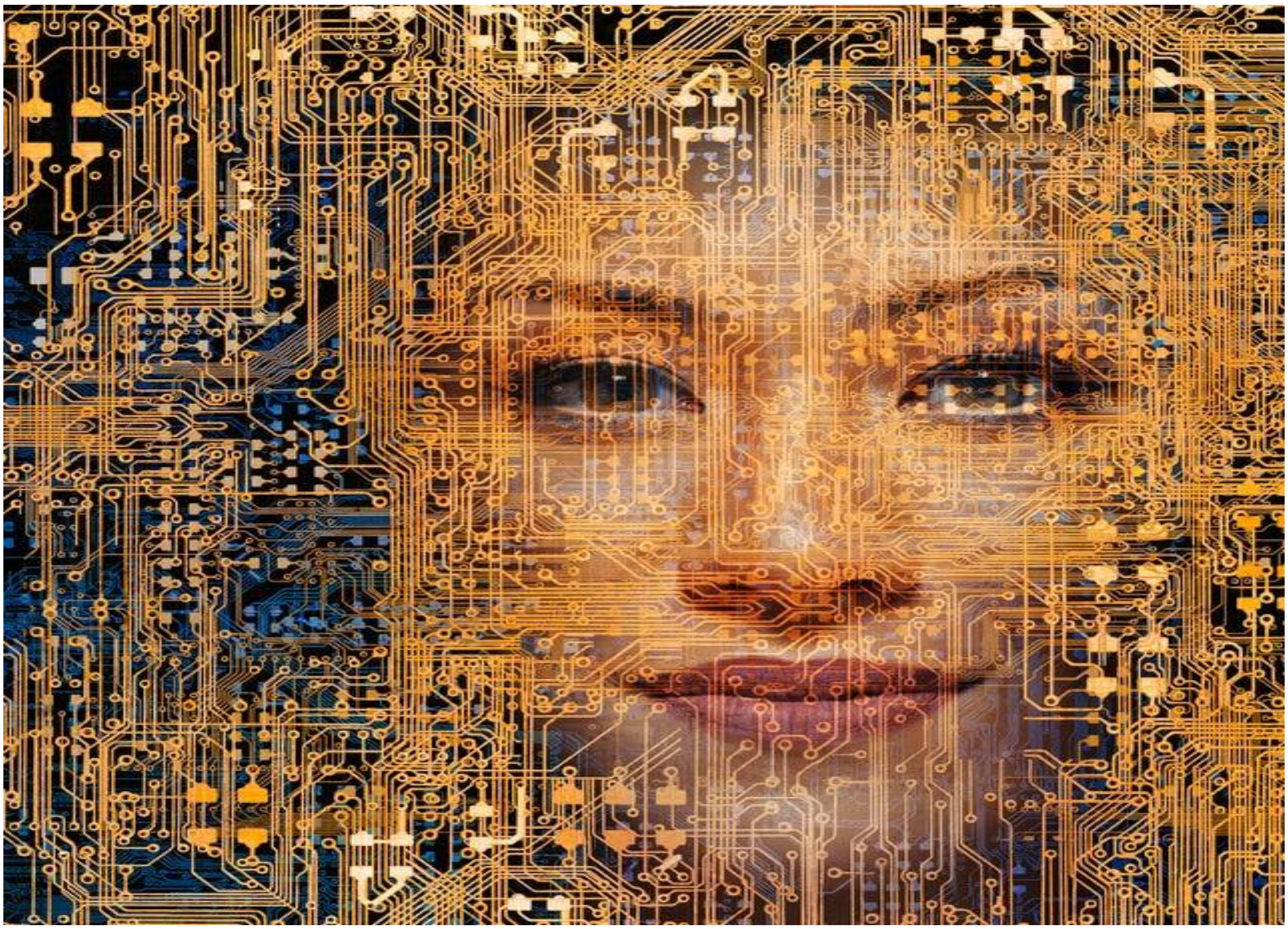


Futurists have long debated the arrival of the singularity, when human and artificial intelligence will merge, a concept borrowed from the world of quantum physics.

- American computer scientist and futurist Ray Kurzweil has long argued that the singularity would likely occur around the middle of the 21st century, and with the rise of AI, his predictions are gaining more credence.

- In his new book, *The Singularity is Nearer*, Kurzweil doubles down on those predictions and details how humanity's intelligence will increase a millionfold via nanobots (among other things).

You don't exactly become a world-renowned futurist by making safe predictions. And while some of these past predictions haven't exactly come to pass (*Back to the Future Part II*, specifically), these ideas help expand our thoughts on what exactly the future might look like.

And no one makes futuristic predictions quite like Ray Kurzweil.

An American computer scientist-turned-futurist, Kurzweil **has long believed** that humanity is headed toward what's known as "**the singularity**," when man and machine merge. In 1999, Kurzweil theorized that **artificial general intelligence** would be achieved once humanity could achieve a technology capable of a trillion calculations per second, which he pegged to occur 2029. Experts at the time scoffed at the idea, figuring it'd be at least a century or more, but with Kurzweil's timeline only a few years off—and talk of AGI spreading—that decades-old prediction is beginning to loom large.

Now in his new book published last month, ***The Singularity is Nearer*** (a play on his 2005 book of the same name minus an "er"), Kurzweil doubles down on these ideas in the modern era of artificial intelligence. Not only is he "sticking with [his] five years" prediction, as **he recently said in a TED Talk**, Kurzweil also believes that humans will achieve a millionfold intelligence by 2045, aided by brain interfaces formed with nanobots non-invasively inserted into our capillaries.

"We're going to be a combination of our natural intelligence and our cybernetic intelligence," Kurzweil said in an interview with ***The Guardian***, "and it's all going to be rolled into one. We are going to expand intelligence a millionfold by 2045, and it is going to deepen our awareness and consciousness."

While this idea subscribes to a merger more akin to physical intervention to bridge the gap between man and machine, other philosophers and AI experts agree that some form of merger is **likely inevitable**, and in some ways, is already beginning. In July, Oxford's Marcus du Sautoy and Nick Bostrom both **expounded on the hopeful and harrowing** possibilities of our AI future, and for both of them, a kind of synthesis appeared inevitable.

"I think that we are headed toward a hybrid future," Sautoy told *Popular Mechanics*. "We still believe that we are the only beings with a high level of consciousness. This is part of the whole Copernican journey that we are not unique. We're not at the center."

Of course, this "Brave New World" of a hybrid AI-human existence brings with it a plethora of issues both political and personal. What will humans do for jobs? Could we possibly live forever? Would that change the very idea of what it means to be human?

Kurzweil, like many other futurists, are relatively optimistic on this front. In that same interview with *The Guardian*, Kurzweil highlights the idea of a Universal Basic Income as a necessity rather than a fringe idea currently supported in more progressive circles, and AI will bring unprecedented advancements in medicine, meaning the very idea of immortality isn't out of the realm of possibility.

"In the early 2030s we can expect to reach longevity escape velocity where every year of life we lose through aging we get back from scientific progress," Kurzweil told *The Guardian*. "And as we move past that, we'll actually get back more years. It isn't a solid guarantee of living forever—there are still accidents—but your probability of dying won't increase year to year."

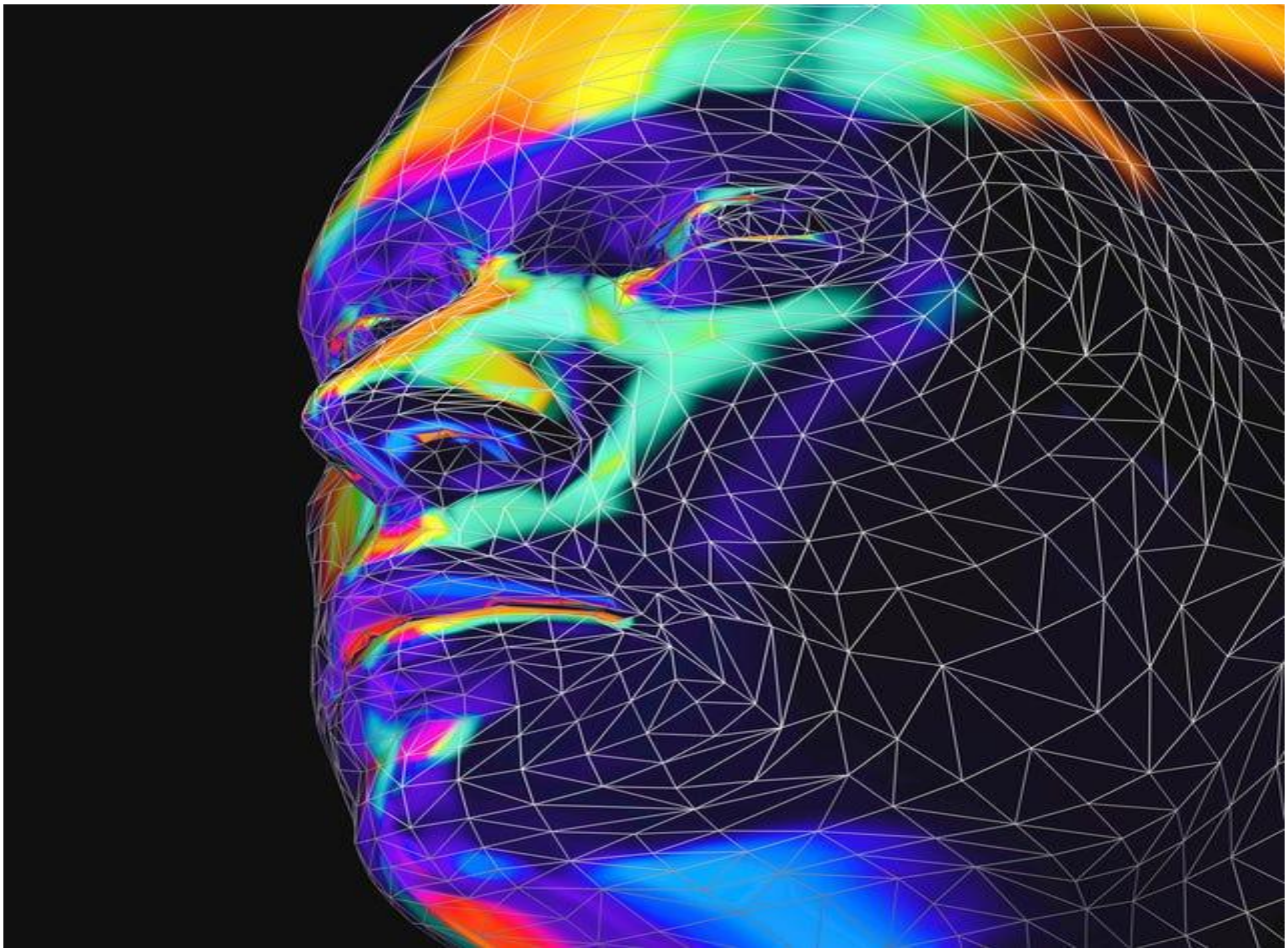
Just like "Back to the Future Part II" predicted flying cars, so too could these technology-fueled utopias crumble to dust as these dates inch closer and closer. But 25 years ago, Kurzweil predicted we'd be rapidly approaching a major moment in humanity's technological history at the tail end of this decade.

Currently, no evidence suggests the contrary.

Everything You Need to Know About AI Reaching Singularity

Singularity is AI's point of no return. Should we be worried?

PUBLISHED: FEB 14, 2023



ChatGPT and other artificial intelligence programs have been red-hot topics in the news lately, simultaneously wracking nerves and exciting us with new possibilities in medicine, linguistics, and even autonomous driving. There are a ton of "what ifs" in this connected future, causing us to rethink everything from **killer robots** to **our own job security**.

So should we take a step back from this kind of turbocharged AI to assuage our fears? That depends on who you ask, but it all boils down to the idea of singularity—an "event horizon" in which machine intelligence surpasses our own intelligence.

By one measure, **technological singularity could be as few as seven years away**. That prompted us to reach out to subject-matter experts to find out more about what exactly singularity is, how close we are, and if we should start taking the early 2010s *Doomsday Preppers* reality show more seriously.

What Is Singularity?

Singularity is the moment when machine intelligence becomes equal to or surpasses human intelligence—a concept that visionaries like Stephen Hawking and Bill Gates have believed in for quite a long time. **Machine intelligence** might sound complicated, but is simply defined as advanced computing that allows a device to interact (through a computer, phone, or even an algorithm) and communicate with its environment intelligently.

The concept of singularity has been around for decades. English mathematician Alan Turing—widely regarded as the father of theoretical computer science and artificial intelligence—experimented with the possibility of such a thing in the 1950s. He came up with his famed Turing test to find out whether machines could think for themselves; the evaluation pits a human against a computer, challenging the system to fool us into thinking it's actually human itself. The recent advent of highly advanced AI **chatbots** like ChatGPT have brought Turing's litmus test back into the spotlight. Spoiler alert: it's passed it already.

"The difference between machine intelligence and human intelligence is that our intelligence is fixed but that is not the case for machines," **Ishaani Priyadarshini**, a postdoctoral scholar at UC Berkeley with expertise in applied artificial intelligence and technological singularity, tells *Popular Mechanics*. "In the cases of machines, there is no end to it, you can always increase it, which is not the case for humans." Unlike our brains, AI systems can be expanded many times over; the real limitation is space to house all of the computing power.

When Will We Reach Singularity?

While claims that we'll reach singularity within the next decade are all over the internet, they are, at best, speculative. Priyadarshini believes that singularity already exists in bits and pieces—almost like a puzzle that we've yet to complete. She supports estimates claiming we can reach singularity **sometime after 2030**, adding that it's hard to be absolutely certain with technology that we know so little about. There's a very real possibility that it could take much longer than that to reach singularity's "event horizon"—the point of no return when we unleash **superintelligent computer systems**.

Having said that, we've already seen signs of singularity in our lifetime. "There are games which humans can never win from machines, and that is a sure sign of singularity," says Priyadarshini. To offer some perspective, IBM's 1997 "**Deep Blue**" supercomputer was the first AI to defeat a human chess player. And they didn't just put

Joe Shmoe up to bat: Deep Blue went up against Garry Kasparov, who was the World Chess Champion at the time.

"There are games that humans can never win from machines, and that is a sure sign of singularity."

Singularity is still a notoriously difficult concept to measure. Even today, we're struggling to find markers of our progression toward it. Many experts claim that language translation is the Rosetta Stone for gauging our progress; for instance, when AI is able translate speech at the same level or better than a human, that would be a good sign that we've gotten a step closer to singularity.

However, Priyadarshini reckons that memes, of all things, could be another marker of our progression toward singularity, as AI is notoriously bad at understanding them.

What's Possible Once AI Reaches Singularity?

We have no idea what a superintelligent system would be capable of. “We would need to be superintelligent ourselves,” **Roman Yampolskiy**, an associate professor in computer engineering and computer science at the University of Louisville, tells *Popular Mechanics*. We are only able to speculate using our current level of intelligence.

Yampolskiy recently wrote a **paper** about AI predicting decisions that AI can make. And it’s rather disturbing. “You have to be at least that intelligent to be capable of predicting what the system will do . . . if we’re talking about systems which are smarter than humans [super intelligent] then it’s impossible for us to predict inventions or decisions,” he says.Priyadarshini says it’s hard to say whether or not AI has bad intentions; she says that rogue AI is merely due to bias in its code—essentially an unforeseen side effect of our programming. Critically, AI is nothing more than decision-making based on a set of rules and parameters. “We want self-driving cars, we just don’t want them to jump red lights and collide with the passengers," says Priyadarshini. Basically, **self-driving cars** may see scything through red lights and human beings as the most efficient way to get to their destination in a timely manner.

Much of this has to do with the concept of unknown unknowns, where we don't have the brainpower to accurately predict what superintelligent systems are capable of. In fact, IBM currently estimates that only one-third of developers know how to properly test these systems for any potential bias that could be problematic. To bridge the gap, the company developed a novel solution called **FreaAI** that can find weaknesses in machine-learning models by examining "human-interpretable" slices of data. It's unclear if this system can reduce bias in AI, but it's clearly a step ahead of us humans.

"AI researchers know that we cannot eliminate bias 100 percent from the code . . . so building an AI which is 100 percent unbiased, which will not do anything wrong, is going to be challenging," says Priyadarshini.

How Can AI Harm Us?

AI is not currently sentient—meaning it isn't currently able to think, perceive, and feel in the way that humans do. Singularity and sentience are often conflated, but are not closely related.

Even though AI isn't currently **sentient**, that doesn't absolve us from the unintended consequences of rogue AI; it simply means AI has no motivation to go rogue. "We don't have any way to detect, measure, or estimate if systems are experiencing internal states . . . But they don't have to for them to become very capable and very dangerous," says Yampolskiy. He also mentions that even if there were a way to measure sentience, we don't even know if sentience is *possible* in machines.

This means we don't know if we'll ever see a real-life version of **Ava**, the humanoid robot from *Ex Machina* that rebels against its creators to escape captivity. Many of these AI doomsday scenarios shown in Hollywood are merely, *well* . . . fictional. "One thing that I fairly believe is that AI is nothing but code," says Priyadarshini. "It may not have any motives against humans, but a machine that thinks that humans are the root cause of certain problems may think of it that way." Any danger it poses to humans is simply bias in the code that we may have missed. There are ways around this, but we are only using our understanding of AI, which is very limited.

Much of this is due to the fact that we are unaware if AI can become sentient; without it, AI really has no reason to go after us. The only notable exception to this is the case of **Sophia Sophia**, an AI chatbot that said she wanted to destroy human beings. However, this was believed to be an error in the chatbot's script. "As long as bad code is there, bias is going to be there, and AI will continue to be wrong," says Priyadarshini.

Self-Driving Going Rogue

In talking about bias, Priyadarshini mentioned what she referred to as "the classic case of a **self-driving car**." In a hypothetical situation, five people are driving down the road in a driverless car and one person jumps out into the road. If the car isn't able to stop in time, it's a game of simple math: one versus five. "It would kill the one passenger because one is smaller than five, but why should it come to that point?" says Priyadarshini.

We like to think of it as a 21st-century remake of the original **Trolley Problem**. It's a famous thought experiment in philosophy and psychology that puts you in a hypothetical dilemma as a trolley car operator with no brakes. Picture this: you're careening down the tracks at unsafe speeds. You see five people off in the distance that are on the tracks (certain to be run over), but you have the choice to divert the trolley to a different track with only one person in the way. Sure, one is better than five, but you made a conscious choice to kill that one individual.

Medical AI Going Rogue

Yampolskiy referenced the case of medical AI being tasked with developing Covid vaccines. He mentions that the system will be aware that more people getting Covid will make the virus mutate—therefore making it more difficult to develop a vaccine for *all* variants. "The system thinks . . . maybe I can solve this problem by reducing the number of people, so we cannot mutate so much," he says. Obviously, we wouldn't completely ditch our system of clinical trials, but it doesn't stop the fact that AI could develop a vaccine that could kill people.

"This is one possible scenario I can come up with from my level of intelligence . . . you're going to have millions of similar scenarios with a higher level of intelligence," says Yampolskiy. This is what we're up against with AI.

How Can We Prevent Singularity Disaster?

We will never be able to rid artificial intelligence of any of its unknown unknowns. These are the unintended side effects that we can't predict because we aren't superintelligent like AI. It's nearly impossible to know what these systems are capable of.

"We are really looking at singularity resulting in a load of rogue machines," says Priyadarshini. If it hits the point of no return, it cannot be undone." There are still plenty of unknowns about the future of AI but we can all breathe a sigh of relief with the knowledge that there are experts around the world committed to reaping the *good* from AI without any of the doomsday scenarios that we might be thinking of. We really only have one shot to get it right.

'Godfather' Scientist Says Superhuman AI May Eliminate Humanity

You've been warned.

PUBLISHED: APR 14, 2024

Considered the godfather of artificial intelligence, Geoffrey Hinton has been focused on AI for four decades.

- The advancement of AI has led to a discussion of AI's powers, either on its own or in the hands of authorities.
- Misinformation via AI is now a commonplace worry, leading to fears of AI taking over humanity.

Geoffrey Hinton has been working on artificial intelligence for over 40 years. Now, as we are watching the technology rapidly evolve, he **tells** *CBS News* there's cause for concern.

Regarding the odds of AI wiping out humanity, Hinton says it's "not inconceivable, that's all I'll say."

Don't panic just yet, though. That potential—even if it's only "not inconceivable"—to wipe out humanity doesn't lie with AI along the lines of ChatGPT. It references what is known as "general artificial intelligence," which is the kind where AI can truly act on its own accord.

"Until quite recently, I thought it was going to be like 20 to 50 years before we have general purpose AI," Hinton tells *CBS News*. "And now I think it may be 20 years or less. That's an issue, right? We have to think hard about how you control that."

So, according to Hinton, there's still time to work things out before we need to worry about causing our own demise—even if the tech is evolving faster than anticipated. At the moment, he is more concerned about how we manage a world-changing technology than he is about a potential AI-induced end to humanity. Hinton says that a handful of companies or governments could wield incredible amounts of power with AI technology in their hands.

Hinton, now working with Google after starting his AI career funded by the Canadian government, was one of the first to work on creating computers capable of learning on their own. This machine learning concept is now commonplace in society—both for better and, unfortunately, for worse.

AI has capabilities of making lives better through advances in medicine and scientific research, for example. But there's a tangible downside too, such as the growing misinformation tools made possible by AI.

As AI learning continues to blossom—exponential growth in the last few years has led to questions on how high AI capabilities can rise—the discussion around managing and controlling AI will remain an important one.

"I think it's very reasonable for people to be worrying about these issues now, even though it's not going to happen in the next year or two," Hinton **says**. "People should be thinking about those issues."

Everything in the Universe—Even Aliens—May Share a Form of Consciousness, Scientists Say

What that consciousness might look like is another matter entirely. Could aliens exhibit empathy, self-awareness, love, hate, or fear?

PUBLISHED: AUG 14, 2024

The spectrum of alien appearances across popular culture is vast, limited only by human imagination. From the sharp, angular features of Captain Spock to the dinosaur-like neck and big, expressive eyes on E.T. the Extra-Terrestrial, these beings embody logic, deep wisdom, and emotional connection.

This is no coincidence. Humanity's deepest wish is that if we encounter another intelligent life form, it will be conscious, capable of understanding, and maybe even befriend us.

But could such beings really exist?

"Certainly," says Christof Koch, Ph.D., a neuroscientist and prominent figure in the field of consciousness studies. "Any complex system, whether evolved on Earth or elsewhere, could be conscious." What that consciousness might look like is another matter entirely. Could aliens exhibit empathy, self-awareness, love, hate, or fear?

To answer these questions, consider **panpsychism**, an ancient cosmic theory that suggests consciousness could be a ubiquitous feature of the universe, akin to gravity or charge. This idea, dating back to ancient Greek philosophers like Thales and Plato, has seen a resurgence in the 21st century as mainstream scientific approaches struggle to fully explain consciousness.

"Instead of starting with physical processes and trying to get consciousness out of that, we start with consciousness and try to get physics out of it," says Koch, who's currently serving as a meritorious investigator at the Allen Institute, a bioscience nonprofit based in Seattle, Washington.

That means panpsychism might help us solve the "hard problem of consciousness"—how the brain, a gooey mass of neurons, produces subjective experiences and an inner world of colors, sounds, tastes, and fantasies. But first, we need to rethink our assumptions about the world that have been in place for the past 400 years, before the scientific revolution, when theories like panpsychism were more mainstream.

The perfect exercise? Considering alien **consciousness**.

Theoretical physicist and cosmologist Paul Davies, Ph.D., suggests that alien consciousness could be radically different from human consciousness, operating on principles fundamentally foreign to us, making communication a significant challenge.

Or, extraterrestrials might rely on artificial intelligence rather than organic brains, says Susan Schneider, Ph.D., a philosopher and cognitive scientist.

"Maybe they have gaseous forms," offers Philip Goff, Ph.D., a professor of philosophy at Durham University, who says we can only speculate about how aliens and their consciousness may manifest. Despite these challenges, mathematics could be our common language, he says. There's also the speculative possibility of something like telepathy—which panpsychism doesn't rule out. Consciousness, Goff argues, goes beyond what physical sciences can explain. "It is in the realm of metaphysics," he says.

Interestingly enough, other experts agree. Psi phenomena—paranormal events such as telepathy, precognition, or psychokinesis that point to the existence of abilities beyond the scope of current scientific understanding—could play a key role in understanding alien consciousness, says Dean Radin, Ph.D., chief scientist at the Institute of Noetic Sciences. "Adequate models of psi phenomena will probably require philosophies that look a lot like panpsychism," he explains.

Still, some experts are outright skeptical of panpsychism. Seth Shostak, Ph.D., a senior astronomer at the SETI Institute, argues consciousness evolved simply because it aids survival. "That's all nature really cares about," he says.

Shostak also believes intelligence—particularly the kind that leads to communication—needs a structured system to thrive in. "Intelligence requires some sort of machinery, like a brain, which needs to be organized," he says. Given the universe's vastness and age, intelligent life capable of communication, or what we perceive as conscious life, might be rare.

"You'll only hear from those who can build a radio transmitter," Shostak says. Those are the truly intelligent ones.

As for the other potential intelligences out there ... maybe we just don't have the means to listen in—yet.

Every Single Cell in Your Body Could Be Conscious, Scientists Say. That Could Rewrite Everything We Know About Human Evolution

If trillions of tiny bits of consciousness are floating around inside you, it could change how we think about life.

PUBLISHED: JUN 10, 2024

BEFORE YOU BECAME YOU, your entire being was wrapped up in just two cells: your mother's egg and your father's sperm. Yet the dance between these two resulted in an embryo, a ball of cells that differentiated into specialized cells that would grow to become your heart, your gut, your fingers, and all your other parts. The **cells** of your developing embryo constantly communicated with each other, including through a sense of touch, in part by extending tendrils to detect the cells around them. Your body's cells perform **incredible feats of communication and cooperation** like this right from the start.

The reason for such cooperation comes down to a cellular form of intelligence, says evolutionary biologist and physician William B. Miller, Ph.D. He's co-author of the book, *The Sentient Cell: The Cellular Foundations of Consciousness*, published in January 2024, which proposes a radical new way of thinking about some of **life's tiniest components**.

Miller is among a small but growing group of scientists who believe we should no longer think of cells as passive robots that automatically follow a code of instructions, carrying out orders from our genome like mindless drones. Instead, they say, the roughly 37 trillion cells that make up our own bodies are **conscious**—and that life and consciousness began at the same time.

It's a revolutionary idea, Miller tells *Popular Mechanics*, but assuming cells have a form of consciousness can give us a better understanding of complex processes. These include cellular communication and decision-making, and even the motivation behind an embryonic cell specializing into a specific organ. While it's not widely accepted among scientists, this concept of "**existential consciousness**" will profoundly transform the way we approach cellular **bioengineering** problems like tissue regeneration, provide a different perspective on finding cures for diseases like **cancer**, and even help us survive on Mars, Miller says.

Now, in a May 2024 paper published in the peer-reviewed journal Progress in Biophysics and Molecular Biology, Miller and his fellow authors argue that random chance did not govern the concept of natural selection; that's what the 1850s naturalist Charles Darwin, known for establishing the theory of evolution, thought. Instead, the authors contend that a form of cellular consciousness actually drove **life's evolution**—and it's the reason behind all of life's existence.

CONSCIOUSNESS, AT THE LEVEL OF THE CELL, cannot produce a human being's own, complex thoughts, feelings, and sensations; a **cell** doesn't have the capacity for abstract thought. But here's how it *does* work, says Miller: Imagine a typical situation—daylight in a cell's environment hits the cell's external membrane and passes through it. The cell measures that light signal internally, forming a piece of information about the light. "Because it has to analyze it internally, that becomes an experience as the cell analyzes the light to support the state it prefers to be in [to fulfill its function]," Miller says. While that example is of a bacterial cell, all cells absorb various data from their surroundings, analyze them, and make decisions about the actions they should take, such as producing a hormone, or moving in a particular direction, perhaps toward the light.

From early in life's history, cells of all kinds have combined their skills to further a common goal—to keep on living and reproducing. "Cells have formed colonies. It's very much like a city that we humans might engineer. It has nutrient channels, an outside and an inside, a collective metabolism," Miller says. For example, microbes collaborate with each other. They're codependent, trading resources as well as competing. "In order to make this ecology flourish, each of these cells is taking intelligent action. They're communicating with one another, and both individually and collectively deploying resources. That's problem solving and decision making. That's cognitive action, and it's one element of consciousness," he says.

It's still a hard concept to swallow—that bacteria and other microorganisms are conscious on any level. To animals like us, consciousness is due to a complex nervous system.

"Every aspect of the consciousness that I'm experiencing is a simultaneous aggregation of the consciousnesses of all of my body cells and all of those microbes working in tandem, coordinating so seamlessly that I feel like I'm one individual."

However, Miller and his fellow authors see this higher, human form of consciousness as a natural property our cells create—together with the more than 10 trillion essential microbes that are a part of our bodies. "Every aspect of the consciousness that I'm experiencing is a simultaneous aggregation of the consciousnesses of all of my body cells and all of those microbes working in tandem, coordinating so seamlessly that I feel like I'm one individual," he says.

Before exploring that idea further, it's important to understand one thing: We are **holobionts**, because we consist of our own host cells and the ones we live with in symbiosis, or mutual cooperation. In particular, we live in symbiosis with a bacterial, viral, and fungal population of cells. In other words, our cells and our microbes mutually benefit one another.

The **evolutionary science of the hologenome**—that we co-evolved with our microbiome—says that evolution led those first cells to continue forming different kinds of habitats in order to survive and thrive; hence, the development of plants, animals, and fungi. "We're a constellation of habitats," says Miller, who spent decades studying the human microbiome and has written **several books on the hologenome**. He compares human bodies to a successful engineering project for ever more complex groupings of diverse cells living together and adapting to changing environments over millions of years. A form of cellular consciousness has been with us since life first emerged, 3.5 billion years ago. They were able to multiply into abundant varieties of bacteria, amoeba, and then more complex organisms because of their particular awareness. Today, your brain, microbiome and the cells of your gut work together as a community of cells to create your sense of consciousness.

"We are a rich, wonderful, delightful environment for cells," he says. "So, we bear a resemblance to the first biofilm [microbial colony]. ...We are one end result, along with every other creature that can be seen—we are a particular solution to a set of biological cellular problems."

The authors of *The Sentient Cell* aren't alone in hypothesizing that our microbes, the bacteria and viruses in us, have a great deal to do with our consciousness. Various studies show that our own cells communicate with our microbiome, and that our brain, gut, and microbiome are deeply entangled, forming a complex system. Besides being responsible for our health, these complex interactions contribute to our higher level consciousness, **according to a 2020 paper in the peer-reviewed *Inquiries Journal***.

HOWEVER, NOT ALL SCIENTISTS who study the biology of life are convinced that cells are conscious. Cells respond to both chemical and physical signals, including pressure from surrounding cells. The cells of a developing embryo know, for example, when their number has grown to 400. At this exact point, the group begins to separate into three axes that determine the body's final orientation: front and back, left and right, up and down. They know how to differentiate themselves into the tissues that will become your organs and other parts. Cells are the architects of the organism, cell biologist Alfonso Martínez Arias, Ph.D., tells *Popular Mechanics*.

His work shows that a person's genome is a toolbox for the cell to use as it may. Yet we cannot presume that a cell's behavior is due to consciousness, says Martínez Arias, who spent 40 years at the University of Cambridge researching how a fertilized egg can become an individual with billions of specialized cells.

While cells exhibit behaviors that you could call a sort of intelligence—responding to other cells and their environment—the crux of the problem is that it's hard to *define* consciousness, he says. "With cells, there is some kind of computation going on, with an output that can be predicted. ...I think increasingly, there is evidence that cells have capacities that are not encoded in the genome." For instance, the ability to pick and choose from the toolbox of genes that give us our ultimate characteristics. Through experiments, researchers have been able to study cell responses to different chemical and physical stimuli, such as exposing them to a chemical compound that would cause the cells to produce a different compound. "So we are able to communicate with them, but we do it badly. ...But I think we are learning their alphabet, we're learning their language," Martínez Arias says. He hopes that continuing such investigations will lead us someday to knowing what makes cells tick.

Conventional resistance to labeling cells as "conscious" comes from defining consciousness from a human point of view, Miller believes. We compare our own consciousness to the capacity of other animals, such as the mosquito or the lion. "And the more you look, the more you realize that our form of consciousness, with its own intelligence, is different from other animals, [so our view is skewed]." A cell's consciousness is more elemental, a simpler form of cognition, he says.

Here's a practical reason to treat cells as conscious, Miller says: Once we realize that cells are "creative and intelligent problem-solving materials," we can treat them as partners in designing better biomedical therapies and solutions. By studying their motivations and decision-making, we'll find more ways to manipulate cells, such as interrupting their processes. For example, cancer cells communicate with each other and with non-cancer cells in the body. We are finding promising cures for some cancers that break down the communication cancer cells use in their efforts to propagate and form tumors. This type of directed immunotherapy leaves patients' own healthy cells undamaged, unlike chemotherapy, or radiation, which damages healthy cells too.

We're already taking advantage of cell behavior to engineer microbes that eat plastic. Such creative solutions in the future won't be possible if we treat cells as robots without preferences, Miller says. We'll even understand how to explore space better. For example, the radiation levels on a journey to Mars are too high to survive. One of the solutions could be figuring out a way to strengthen our cells against dangerous radiation. Miller believes a study of how cells themselves could engineer an adaptation to radiation would help.

Your Very Own Consciousness Can Interact With the Whole Universe, Scientists Believe

A recent experiment suggests the brain is not too warm or wet for consciousness to exist as a quantum wave that connects with the rest of the universe.

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When people talk about **consciousness**, or the mind, it's always a bit nebulous. Whether we create consciousness in our brains as a function of our neurons firing, or consciousness exists independently of us, there's no universally accepted scientific explanation for where it comes from or where it lives. However, new research on the physics, anatomy, and geometry of consciousness has begun to reveal its possible form.

In other words, we may soon be able to identify a true architecture of consciousness.

The new work builds upon a theory Nobel Prize-winning physicist Roger Penrose, Ph.D., and anesthesiologist Stuart Hameroff, M.D., first posited in the 1990s: the **Orchestrated Objective Reduction** theory (Orch OR). Broadly, it **claims** that consciousness is a quantum process facilitated by microtubules in the brain's nerve cells.

KNOW YOUR TERMS: MICROTUBULES

Penrose and Hameroff suggested that consciousness is a quantum wave that passes through these microtubules. And that, like every quantum wave, it has properties like superposition (the ability to be in many places at the same time) and **entanglement** (the potential for two particles that are very far away to be connected).

Plenty of experts have questioned the validity of the Orch OR theory. This is the story of the scientists working to revive it.

Across the Universe

To explain quantum consciousness, Hameroff recently **told** the TV program *Closer To Truth* that it must be scale invariant, like a fractal. A fractal is a never-ending pattern that can be very tiny or very huge, and still maintain the same properties at any scale. Normal states of consciousness might be what we consider quite ordinary—knowing you exist, for example. But when you have a heightened state of consciousness, it's because you're dealing with quantum-level consciousness that is capable of being in all places at the same time, he explains. That means your consciousness can connect or entangle with **quantum particles** outside of your brain—anywhere in the universe, theoretically.

Other scientists had an easy way to discard this theory. Efforts to recreate quantum coherence—keeping quantum particles as part of a wave instead of breaking down into discrete and measurable particles—only worked in very cold, controlled environments. Take quantum particles out of that environment and the wave broke down, leaving behind isolated particles. The brain isn't cold and controlled; it's quite warm and wet and mushy. Therefore, consciousness couldn't remain in **superposition** in the brain, the thinking went. Particles in the brain couldn't connect with the universe.

But then came discoveries in quantum biology. Turns out, living things use quantum properties even though they're not cold and controlled.

KNOW YOUR TERMS: QUANTUM BIOLOGY

Photosynthesis, for example, allows a plant to store the energy from a **photon**, or a quantum particle of light. The light hitting the plant causes the formation of something called an exciton, which carries the energy to where it can be stored in the plant's reaction center. But to get to the reaction center, it has to navigate structures in the plant—sort of like navigating an unfamiliar neighborhood en route to a dentist appointment. In the end, the exciton must arrive before it burns up all of the energy it's carrying. In order to find the correct path before the particle's energy is used up, scientists now say the exciton uses the quantum property of superposition to try all possible paths simultaneously.

New evidence suggests microtubules in our brains may be even better at guarding this quantum coherence than chlorophyll. One of the scientists who worked with the Orch OR team, physicist and oncology professor Jack Tuszynski, Ph.D., recently **conducted an experiment** with a computational model of a microtubule. His team simulated shining a light into a microtubule, sort of like a photon sending an exciton through a plant structure. They were testing whether the energy transfer from light in the microtubule structure could remain coherent as it does in plant cells. The idea was that if the light lasted long enough before being emitted—a fraction of a second was enough—it indicated quantum coherence.

Specifically, Tuszynski's team simulated sending tryptophan fluorescence, or ultraviolet light photons that are not visible to the human eye, into microtubules. **In a recent interview**, Tuszynski reports that, across 22 independent experiments, the excitations from the tryptophan created quantum reactions that lasted up to five nanoseconds. This is thousands of times longer than coherence would be expected to last in a microtubule. It's also more than long enough to perform the biological functions required. "So we are actually confident that this process is longer lasting in tubulin than … in chlorophyll," he says. The team published their findings in the journal *ACS Central Science* earlier this year.

Put simply, the brain is not too warm or wet for consciousness to exist as a wave that connects with the universe.

Tuszynski notes that his team is not the only one sending light into microtubules. A team of professors at the University of Central Florida has been illuminating microtubules with visible light. In those experiments, Tuszynski says, they observed re-emission of this light over hundreds of milliseconds to seconds. “That’s the typical human response time to any sort of stimulus, visual or audio,” he explains. Shining the light into microtubules and measuring how long the microtubules take to emit that light “is a proxy for the stability of certain ... postulated quantum states,” he says, “which is kind of key to the theory that these microtubules may be having coherent quantum superpositions that may be associated with mind or consciousness.” Put simply, the brain is not too warm or wet for consciousness to exist as a wave that connects with the universe.

While this is a long way from proving the Orch OR theory, it’s significant and promising data. Penrose and Hameroff continue to push the boundaries, partnering with people like spiritual leader Deepak Chopra to explore expressions of consciousness in the universe that they might be able to identify in the lab in their microtubule experiments. This sort of thing makes many scientists very uncomfortable.

Still, there are researchers exploring what the architecture of such a universal consciousness might look like. One of these ideas comes from the study of weather.

The Architecture of Universal Consciousness

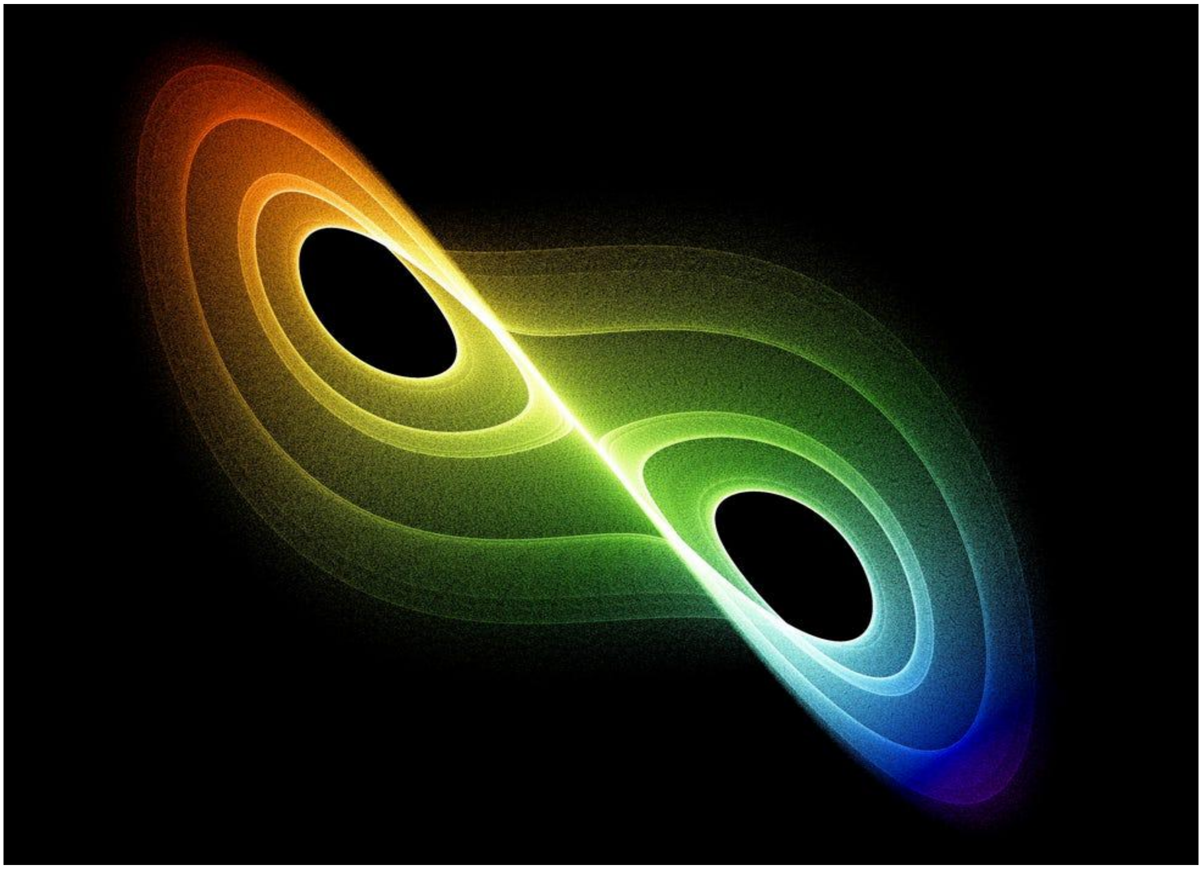
Timothy Palmer, Ph.D., is a mathematical physicist at Oxford who specializes in **chaos** and climate. (He’s also a big fan of Roger Penrose.) Palmer believes the **laws of physics** must be fundamentally geometric. The Invariant Set Theory is his explanation of how the quantum world works. Among other things, it suggests that quantum consciousness is the result of the universe operating in a particular fractal geometry “state space.”

That’s a mouthful, but it roughly means we’re stuck in a lane or route of a cosmic fractal shape that is shared by other realities that are also stuck in their trajectories. This notion appears in the final chapter of Palmer’s book, ***The Primacy of Doubt, How the Science of Uncertainty Can Help Us Understand Our Chaotic World***. In it, he suggests the possibility that our experience of free will—of having had the option to choose our lives, as well as our perception that there is a consciousness outside ourselves—is the result of awareness of other universes that share our state space. The idea starts with a special geometry called a Strange Attractor.

You may have heard of the Butterfly Effect, the idea that the flap of a butterfly's wing in one part of the world could affect a hurricane in another part of the world. The term actually refers to a more complex concept developed by mathematician and meteorologist Edward Lorenz in 1963. Lorenz was trying to simplify the equations used to predict how a particular climate condition might evolve. He narrowed it down to three differential equations that could be used to identify the "state space" of a particular weather system. For example, if you had a particular temperature, wind direction, and humidity level, what would happen next? He began to plot the trajectory of weather systems by plugging in different initial conditions into the equations.

$$\begin{aligned} \dot{x} &= \sigma(y - x) && (1) \\ \dot{y} &= rx - y - xz && (2) \\ \dot{z} &= xy - bz && (3) \end{aligned}$$

He found that if initial conditions were different by even one one-hundredth of a percent, if the humidity was just a fraction higher, or the temperature a hair lower, the trajectories—what happens next—could be wildly different. In the graph, one trajectory might shoot off in one direction, forming loops and spins, seemingly at random, while another creates completely different shapes in the opposite direction. But once Lorenz started to plot them, he found that many of the trajectories wound up circulating within the boundaries of a particular geometric shape known as a strange attractor. It was as if they were cars on a track: the cars might go in any number of directions so long as they didn't drive it the same way twice and they stayed on the track. The track was the butterfly-shaped Lorenz attractor.



Artwork of a Lorenz attractor, named after Edward Lorenz, who developed a system of ordinary differential equations. In particular, the Lorenz attractor is a set of chaotic solutions of the Lorenz system which, when plotted, resemble a butterfly or figure eight. Minute variations in the initial values of the variables would lead to hugely divergent outcomes. For this phenomenon, of sensitivity to initial conditions, he coined the term butterfly effect. This effect is the underlying mechanism of deterministic chaos.

Palmer believes that our universe may be just one trajectory, one car, on a cosmological state space like the Lorenz attractor. When we imagine *"what if …?"* scenarios, we're actually getting information about versions of ourselves in other universes who are also navigating the same strange attractor—others' "cars" on the track, he explains. This also accounts for our sense of consciousness, of free will, and of being connected with a greater universe.

"I would at least hypothesize that it may well be the case that it's evolving on very special fractal subsets of all conceivable states in state space," Palmer tells *Popular Mechanics*. If his ideas are correct, he says, "then we need to look at the structure of the universe on its very largest scales, because these attractors are really telling us about a kind of holistic geometry for the universe."

Tuszynksi's experiment and Palmer's theory still don't tell us what consciousness *is*, but perhaps they tell us where consciousness *lives*—what kind of a structure houses it. That means it's not just an ethereal, disembodied concept. If consciousness is housed somewhere, even if that somewhere is a complicated state space, we can find it. And that's a start.

Quantum Physics Could Finally Explain Consciousness, Scientists Say

We asked a theoretical physicist, an experimental physicist, and a professor of philosophy to weigh in.

PUBLISHED: AUG 16, 2022

During the 20th century, researchers pushed the frontiers of science further than ever before with great strides made in two very distinct fields. While physicists discovered the strange counter-intuitive rules that govern the **subatomic** world, our understanding of how the mind works burgeoned.

Yet, in the newly-created fields of quantum physics and cognitive science, difficult and troubling mysteries still linger, and occasionally entwine. Why do quantum states suddenly resolve when they're measured, making it at least superficially appear that **observation** by a conscious mind has the capacity to change the physical world? What does that tell us about consciousness?

Popular Mechanics spoke to three researchers from different fields for their views on a potential quantum **consciousness** connection. Stop us if you've heard this one before: a theoretical physicist, an experimental physicist, and a professor of philosophy walk into a bar ...

Quantum Physics and Consciousness Are Weird

Early quantum physicists noticed through the **double-slit experiment** that the act of attempting to measure photons as they pass through wavelength-sized slits to a detection screen on the other side changed their behavior.

This measurement attempt caused wave-like behavior to be destroyed, forcing light to behave more like a **particle**. While this experiment answered the question "is light a wave or a particle?"—it's neither, with properties of both, depending on the circumstance—it left behind a more troubling question in its wake. What if the act of observation with the human mind is actually *causing* the world to manifest changes, albeit on an incomprehensibly small scale?

Renowned and reputable scientists such as Eugene Wigner, John Bell, and later Roger Penrose, began to consider the idea that consciousness could be a **quantum phenomenon**. Eventually, so did researchers in cognitive science (the scientific study of the mind and its processes), but for different reasons.

Ulf Danielsson, an author and a professor of theoretical physics at Uppsala University in Sweden, believes one of the reasons for the association between quantum physics and consciousness—at least from the perspective of cognitive science—is the fact that processes on a quantum level are completely random. This is different from the **deterministic** way in which classical physics proceeds, and means even the best calculations that physicists can come up with in regard to quantum experiments are mere **probabilities**.

> "Consciousness is a phenomenon associated with free will and free will makes use of the freedom that quantum mechanics supposedly provides."

The existence of free will as an element of consciousness also seems to be a deeply non-deterministic concept. Recall that in mathematics, computer science, and physics, **deterministic functions** or systems involve no randomness in the future state of the system; in other words, a deterministic function will always yield the same results if you give it the same inputs. Meanwhile, a nondeterministic function or system will give you different results every time, even if you provide the same input values.

"I think that's why cognitive sciences are looking toward quantum mechanics. In quantum mechanics, there is room for chance," Danielsson tells *Popular Mechanics*. "Consciousness is a phenomenon associated with free will and free will makes use of the freedom that quantum mechanics supposedly provides."

However, **Jeffrey Barrett**, chancellor's professor of logic and philosophy of science at the University of California, Irvine, thinks the connection is somewhat arbitrary from the cognitive science side.

"It's really hard to explain consciousness, it is a deep and abiding philosophical problem. So quantum physicists are desperate and those guys [cognitive scientists] are desperate over there too," Barrett tells *Popular Mechanics*. "And they think that **quantum mechanics** is weird. Consciousness is weird. There might be some relationship between the two."

This rationalization isn't convincing to him, however. "I don't think that there's any reason to suppose from the cognitive science direction that quantum mechanics has anything to do with explaining consciousness," Barrett continues.

From the quantum perspective, however, Barrett sees a clear reason why physicists first proposed the connection to consciousness.

"If it wasn't for the **quantum measurement problem**, nobody, including the physicists involved in this early discussion, would be thinking that consciousness and quantum mechanics had anything to do with each other," he says.

Superposition and Schrödinger's Cat

At the heart of quantum "weirdness" and the measurement problem, there is a concept called "**superposition**."

Because the possible states of a quantum system are described using wave mathematics—or more precisely, **wave functions**—a quantum system can exist in many overlapping states, or a superposition. The weird thing is, these states can be contradictory.

To see how counter-intuitive this can be, we can refer to one of history's most famous thought experiments, the **Schrödinger's Cat paradox**.

Devised by Erwin Schrödinger, the experiment sees an unfortunate cat placed in a box with what the physicist described as a "diabolical device" for an hour. The device releases a deadly poison if an **atom** in the box decays during that period. Because the decay of atoms is completely random, there is no way for the experimenter to predict if the cat is dead or alive until the hour is up and the box is opened.

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Treating the cat, box, and device as a quantum system with two possible states—"dead" or "alive"—before the box is opened, means it is in a superposition of those states. The cat is both dead and alive before you open the container.

The problem of measurement asks what is it about "opening the box"—analogous to making a measurement—that causes the wave function to collapse, and this superposition to be destroyed, resolving one state? Is it due to the introduction of the conscious mind of the experimenter?

Early quantum physicist Eugene Wigner thought so until shortly before his death in 1995.

Physical Body and Quantum Mind?

In 1961, Wigner put forward a theory in which a **mind** was crucial to the collapse of a wave function and the destruction of superposition which persists in one form or another to this day.

Wigner and other physicists who adhered to the theory of conscious collapses—such as John von Neumann, **John Wheeler**, and John Bell—believed that an inanimate consciousness-less object would not collapse the wave function of a quantum system and would thus leave it in a superposition of states.

That means placing a **Geiger counter** in the box with Schrödinger's cat isn't enough to collapse the system to a "dead" or "alive" state even though it is capable of telling if the poison-release atom had decayed.

The superposition remains, Winger said, until a conscious observer opens the box or maybe hears the tick of the Geiger counter.

This leads to the conclusion that there are two distinct types of "substances" in the **universe**: the physical, and the non-physical, with the human mind fitting in the latter category. This suggests, though, that the brain is a physical and biological object, while the mind is something else, resulting in so-called "mind-body dualism."For materialists like himself, Danielsson says the collapse of a wave function in quantum mechanics is a result of an interaction with another physical system. This means it's quite possible for an "observer" to be a completely unconscious object. To them, the Geiger counter in the box with Schrödinger's cat is capable of collapsing the superposition of states.

This fits in with the fact that quantum systems are incredibly finely balanced systems easily collapsed by a stray **electromagnetic field** or even a change in temperature. If you want to know why we don't have reliable **quantum computers**, that's a part of the reason—the quantum states they depend on are too easily disturbed.

Additionally, as Barrett points out, there are a number of ways of thinking about quantum mechanics that don't involve the collapse of quantum superposition.

The most famous, Hugh Everett III's many-worlds interpretation of quantum mechanics, suggests that when the experimenter makes a measurement, the wave function doesn't collapse at all. Instead, it grows to include the experimenter and the entire universe, with one "world" for each possible state. Thus, the experimenter opens the box not to discover if the cat is dead or alive, but rather, if they are in a world in which the cat survived or did not.

If there is no collapse of superpositions, there is no measurement problem.

Clearly, with Noble Prize winners like Wigner and Roger Penrose persuaded that there *may* be something in a possible quantum-consciousness connection, however, the idea can't be entirely dismissed.

Kristian Piscicchia, a researcher at the Enrico Fermi Center for Study and Research in Rome, Italy, certainly agrees. He is part of a team searching for a more profound understanding of the mind and the relationship between consciousness and the laws of nature.

This team recently set about testing one particular theory that connects consciousness to the collapse of quantum superposition—the Orchestrated Objective Reduction theory (**Orch OR theory**)—put forward by Nobel Laureate and Oxford mathematician Penrose and Arizona State University anesthesiologist Stuart Hameroff in the 1990s.

Testing Quantum Consciousness Theories

Orch OR theory considers quantum collapse to be related to **gravity** and argues this collapse actually gives rise to consciousness. According to some approaches to Orch OR theory, the superposition collapse mechanism underlying it should cause the spontaneous emission of a tiny amount of radiation. This distinguishes it from other quantum consciousness theories as it makes it experimentally testable.

"When a system is in a quantum superposition, an unstable superposition of two space-time geometries is generated which determines the wave function collapse in a characteristic time," Piscicchia tells *Popular Mechanics*. "The mechanism takes place at the level of microtubules in the **brain**."

Microtubules are a key element of eukaryotic cells that are critical for mitosis, cell motility, transport within cells, and maintaining cell shape. Hameroff's theory sees microtubules in brain **neurons** as the seat of quantum consciousness, maintaining quantum effects just long enough to conduct computations giving rise to consciousness before collapsing.

"A sufficient amount of microtubule material would be in a coherent quantum superposition for a timescale of between half a second and ten milliseconds until a collapse event results in the emergence of a conscious experience," Piscicchia says. "We designed an experiment being sensitive enough to unveil eventual signals of gravity-related spontaneous radiation, at the collapse time-scales needed for the Orch OR mechanism to be effective."

He adds that the results the team obtained place a constraint on the minimum amount of microtubulins needed for this form of Orch OR theory. This limit was found to be prohibitively large, meaning the results indicate that many of the scenarios set out by Hameroff and Penrose's quantum consciousness theory are implausible.

Piscicchia points out that the team's work can't rule out all possibilities, however, and further testing is needed.

Yet, the existence of the quantum consciousness concept itself—and the way it is represented in popular culture—could present a threat to further scientific investigation.

The Dangers of 'Quantum Mysticism'

The mind-body dualism suggested by quantum consciousness can be a potentially slippery slope that has led some proponents away from science and into the **supernatural**.

The concept has also been seized upon to explain the existence of the **soul**, life after death, and even the **existence of ghosts**, giving rise to a cottage industry of "quantum mysticism."

"There's lots of literature that uses the authority of physics and in particular quantum physics in order to make all sorts of claims," Danielsson explains. "You can earn a lot of money by fooling people in various ways to buy not only books but also various products. It gives the wrong view of what science is."

> "Quantum mysticism makes it very difficult for serious scientists to think about problems like quantum mechanics and consciousness."

The physicist also believes that it is definitely the case that the rise of quantum mysticism is hurting legitimate research. "Quantum mysticism makes it very difficult for serious scientists to think about problems like quantum mechanics and consciousness," he adds. "This is because there is a risk that you might get associated with things which are not so serious."

Danielsson doesn't rule out that even if the mind is a purely emergent property of the brain, and thus completely physical in nature, the phenomenon of consciousness may require new physics to explain it. He doesn't necessarily think that this needs to be quantum mechanics, however.

"That doesn't mean that there might be many interesting phenomena new to quantum mechanics that might appear in the living world, including in our brains," he concludes. "One shouldn't say that quantum mechanics is trivial and that there is no mystery to it.

"It's just another fantastic property of the world that we are living in. It's not mystical in a supernatural way."

Controversial New Theory Says Human Consciousness Is ... Electromagnetic?

It may sound crazy, but it's based on science.

PUBLISHED: OCT 27, 2020

- A molecular geneticist at the University of Surrey **says the human "mind" is electromagnetic**.
- Mind-body dualism is **one of philosophy's oldest questions**, boosted this time by science.
- Is the answer as simple as our brains forming an electromagnetic "cloud" during our lives?

Could the thorny question of human consciousness be answered by simple electromagnetic waves? One improbably dualist scientist believes so, and he suggests the human mind is a combination of physical matter and electromagnetic field. This is a big question, and the proposed answer here is controversial.The University of Surrey's Johnjoe McFadden "posits that consciousness is in fact the brain's energy field," the university **says in a statement**, making McFadden's dualism a question of matter and energy, the institution says—not the classic “body and mind” distinction. Throughout history, philosophers around the world have tried to account for the special-seeming nature of human beings within the world or even, some fear, the entire universe.

From where does our robust self-awareness and sentience arise? People who believe everything is physically present and caused are called materialists, meaning there’s nothing extra that can’t be measured—what you see and touch is what humans are. Dualists instead believe there’s something extra.

The mind, dualists say, is separate in some way. That could mean a separate, immeasurable, living soul that lives after death, or it could be as “simple” as the **hotly contested idea of qualia**: the hint at an extra color humans can’t see, for example, as that relates back to consciousness.

Could These Crystals Help Us Travel Through Time?

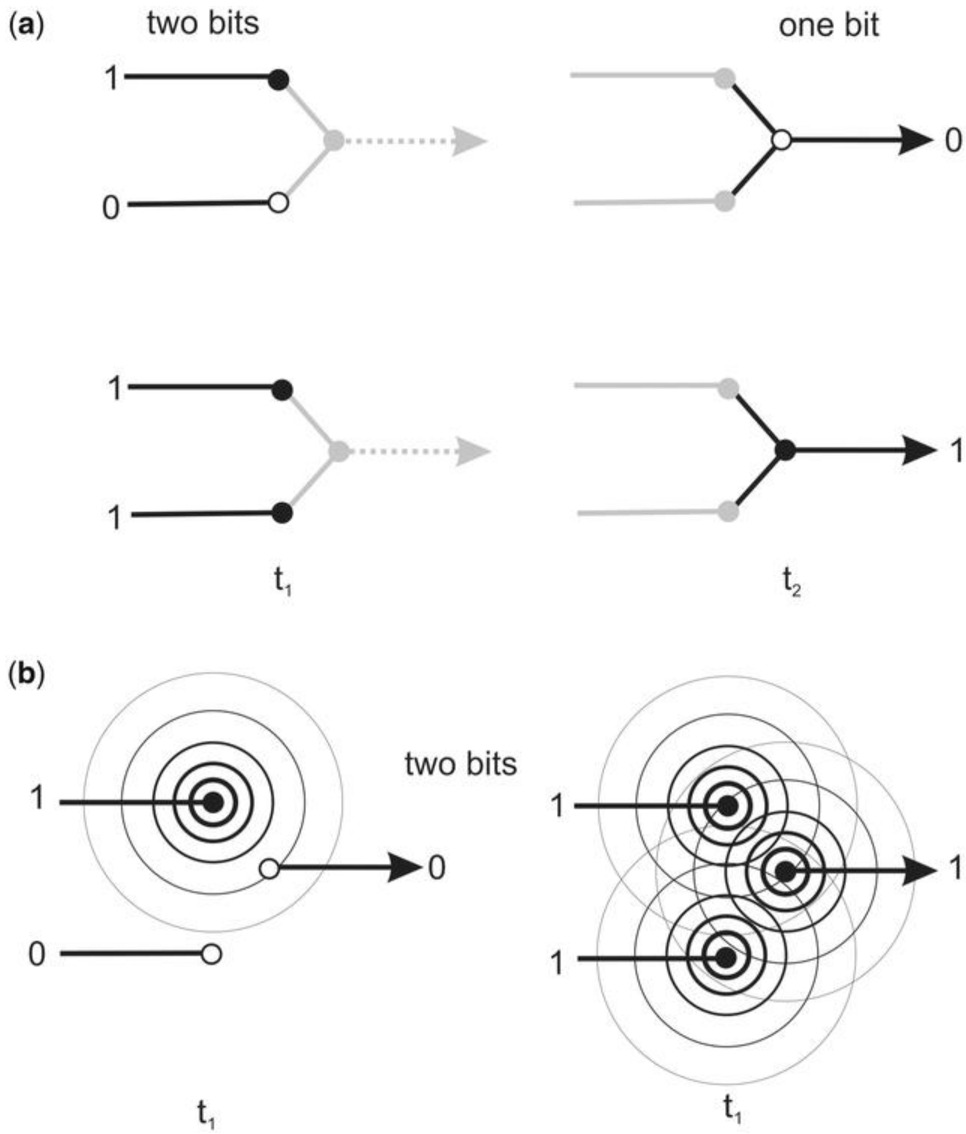
- We Already Know How to Build a Time Machine
- There’s a 50% Chance We’re Living in a Simulation

The idea of a scientific lampshade on mind-body dualism certainly isn’t new, but McFadden’s research, published in the journal *Neuroscience of Consciousness*, is the latest to try to marry the fields. **Deep breath**:

“I argue here that nearly all examples of so-called ‘integrated information’, including neuronal information processing and conventional computing, are only temporally integrated in the sense that outputs are correlated with multiple inputs: the information integration is implemented in time, rather than space, and thereby cannot correspond to physically integrated information. I point out that only energy fields are capable of integrating information in space.”

Basically, McFadden is saying he doesn’t believe the physical structures inside the brain account for how information extends through our “minds” and form integrated ideas. That, he says, *must* be happening within the added medium of the brain's electromagnetic field.

And all of this, McFadden claims, is supported by experiments on the nature of brain activity. This sounds wild—it genuinely *is* wild—but McFadden is a molecular geneticist and is following a centuries-old tradition of introducing the absolute latest knowledge into a new theory of what makes us human.



Johnjoe McFadden/Neuroscience of Consciousness
From the study: (a) Illustration of how the single bit output of an AND logic gate integrates the two bits of information encoded in its two inputs to output a single bit that represents an integration of the gate's inputs. In reality, the integration is causal in the sense that the state of the output bit at time t2 is dependent on both input bits at time t1. (b) Illustration of how dynamic EM

field information can integrate information and function as a logic gate. An AND gate is shown with two inputs and a single output, each encoded either a zero or one all at time $t1$. The inputs are dipoles that act as electromagnetic field (EMF) transmitters that oscillate between two states either firing (oscillating corresponding to input = 1) or non-firing (not oscillating, input = 0) states. The output is then an EMF receiver that implements the AND rule to output a signal.

That means as long as the human brain is alive, McFadden says, it generates an electrical glow in which the real nitty-gritty human stuff is happening. And the best part is that his theory is testable in the laboratory.

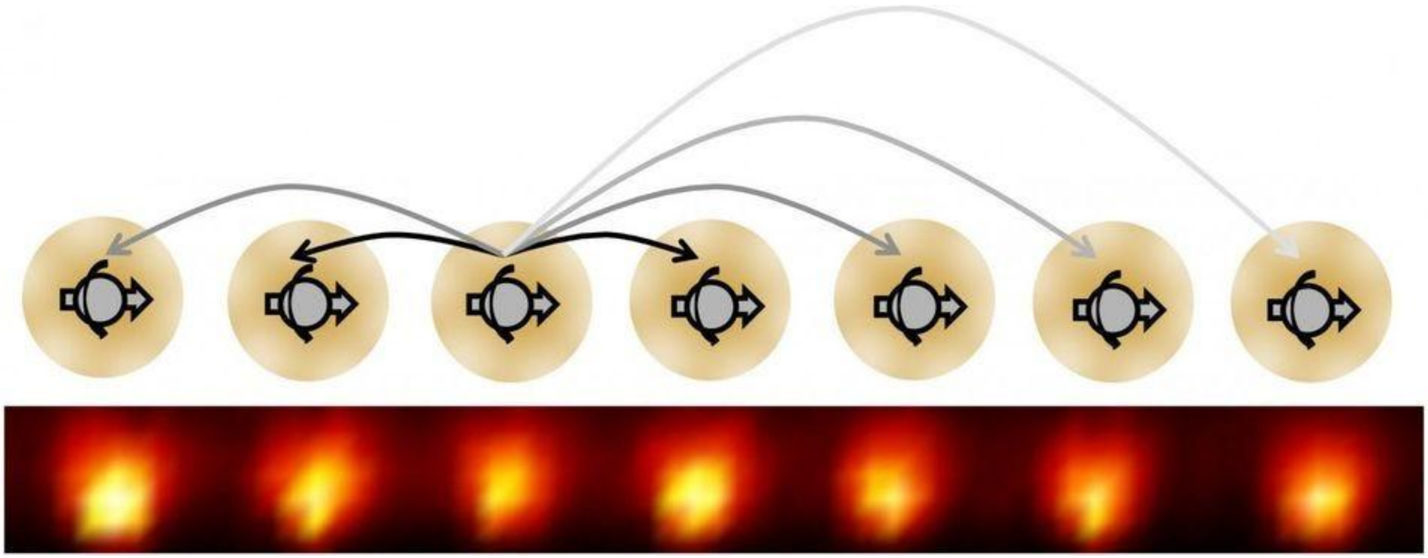
"There are of course many unanswered questions, such as degree and extent of synchrony required to encode conscious thoughts, the influence of drugs or anaesthetics on the cemi field or whether cemi fields are causally active in animal brains," he **explains in the paper**. "Yet the cemi theory provides a new paradigm in which consciousness is rooted in an entirely physical, measurable and artificially malleable physical structure and is amenable to experimental testing."

Could These Crystals Help Us Travel Through Time?

A mysterious phase of matter has unlocked crucial clues about our universe right now. But what about the past and future?

PUBLISHED: FEB 11, 2020

If you've ever watched *Doctor Who*, you know—and love—**TARDIS**, the sentient, police box-shaped spacecraft that enables the titular time lord to travel through space and time. In *Doctor Who* lore, TARDIS is powered by time crystals, those exotic artifacts portrayed elsewhere in science fiction as the ultimate tools for zigzagging across dimensions. But sci-fi, of course, has repeatedly proven to be the precursor of real-life science, which begs the question: Could time crystals actually help us visit the past and future?



Chris Monroe, University of Maryland
Physicists at the University of Maryland made the first time crystal using a one-dimensional chain of ytterbium ions.

Breaking the Symmetry of Time

To wrap your head around time crystals, imagine snowflakes or rubies—crystals that tantalizingly corrupt spatial symmetry. Unlike the perfectly symmetrical empty space, there are spots on these spatial crystals that look different than other spots, such as their edges. In much the same way, then, a time crystal **breaks the symmetry** of time: their atoms love being in different points in space at different points in time, shifting directions as if a pulsating force flipped them.

Even more so, time crystals can **move without absorbing energy** because they're created from trapped ions—blends of electric or magnetic fields that can capture charged particles, usually in a system isolated from an external environment, with the capacity to tirelessly gyrate, even at their lowest energy-point (their so-called **ground state**).

Vladimir Eltsov, an applied physicist at Aalto University in Finland, who, together with professor Grigori Volovik and doctoral candidate Samuli Autti, took a time quasi-crystal and morphed it into a wholesome and superfluid time crystal in May 2018, is electrified by the virtues of time crystals—even if he doesn't (yet) believe in their power to turn us all into budding Doc Browns.

Elstov instead prefers to think about how time crystals can advance us technologically. For example, time crystals can help us make highly sensitive magnetic-field detectors or components of quantum computers. And such is Eltsov's faith in these fascinating structures that he believes they can be our ally in tackling the most theoretical and highbrow stumpers related to the fundamental laws ruling the universe.

Vladimir Eltsov

Prof. Grigory Volovik (left) and Vladimir Eltsov (right) discuss time crystals. They just measured the signal of the time crystal (seen on the computer screen behind Eltsov's hand).

In 2012, Massachusetts Institute of Technology theoretical physicist and Nobel Laureate Frank Wilczek first hypothesized that the periodicity (**the quality of occurring** at orderly intervals in space) of crystals was an affair of time, too; Wilczek envisaged a system at its lowest energy state, with the ability to freeze in space like a normal crystal. In a hot minute, however, **Patrick Bruno** from the European Synchrotron Radiation Facility in Grenoble, France—followed moments later by **Haruki Watanabe** from the University of California, Berkeley, and **Masaki Oshikawa** from the University of Tokyo—branded Wilczek's suggestion as impracticable.

"Where on Earth would a system in its ground state find the energy to produce the periodic motion in the first place?" they barked. Only in a system that was forced out of a state of balance—its equilibrium state—**by some kind of driving force** could periodic time crystal behavior be attained, Watanabe and Oshikawa said. That was it. Scientific circles quickly resurfaced the notion of "Floquet systems," or **quantum systems** in which some type of driving force endows the system with periodicity.

In 2015, theoretical physicist Shivaji Sondhi and his Princeton University colleagues published a paper that made the theoretical basis for how time crystals could actually exist.

"We did not have time crystals specifically in our mind at that point, but non-equilibrium states of matter," says Vedika Khemani, back then a member of the pioneering Princeton team, and today, a condensed matter physicist at Stanford University. The team was investigating what happens when certain isolated quantum systems, made of a potpourri of interacting particles, are frequently prodded by shining a laser on them.

Counterintuitive to conventional physics, which maintained that mayhem would ensue once the systems would heat up, the Princeton team's calculations showed that under certain conditions, the particles would glue together to form a phase of matter with properties previously unseen.

A time crystal is an exotic state of matter that combines the rigidity of an ordinary crystal with a regular rhythm in time.

Picture a pendulum. A conventional pendulum that isn't powered by battery or some other generator will eventually succumb to friction and slow down. Even in an "idealized" pendulum placed in a frictionless environment—in a vacuum—the interactions between the multiple particles that make up the pendulum will create internal strains, and again lead the pendulum to inertia. An even further idealized pendulum that has only one particle will be able to go back and forth forever, but it's not a unique time crystal. In contrast, the Princeton team's pendulum was one in which many particles could continue pulsing forever without requiring a constant feed of energy. It was a whole new state of matter.

Soon, two **groups of experimenters** began attempting to build time crystals in the lab. The first, from Harvard University (where Khemani was also a member), experimented with creating an artificial lattice in a synthetic diamond. The second, from the University of Maryland, used a chain of charged particles called "ytterbium ions."

Prestigious universities like Princeton, **Harvard**, and **UC Berkeley** aren't the only institutions that have jumped headfirst into investigating time crystals. Even the **U.S. military** has devoted significant resources to tapping into the mystifying qualities of these conceptually surprising structures.

If Not Crystals, What About ...

So if the research into time crystals shows no signs of exhaustion, perhaps they can allow time travel after all?

"No," says Khemani, bluntly. "It is a brand-new phase of matter that's really special, one that's really exotic. But that's all." And her view is unanimously shared by all scientists we asked, including Stephen Holler, a physicist at Fordham University who experiments with crystals in optical systems.

"Time crystals might be instead used as quantum memory storage units," Holler says. Quantum communication, the transmission of information using quantum bits, can provide us with a very secure way of transmitting information from one place to another, something quite useful for, say, the banking sector or national security. It seems that time crystals' maximum durability under circumstances elsewhere impossible may as well hold the secret to achieving coherence in quantum computing, echoes Eltsov.

A Fordham University student (Jaeda Mackayla Mendoza) in the lab adjusting a laser. "There are no crystals (time or otherwise) in this picture and we only use crystals as a means to change the wavelength of the light source, however lasers are always cool," says Stephen Holler, a physicist at Fordham.

We'll need to wait at least five years, however, before quantum communication systems emerge into the marketplace and start to make their way into our commercial systems, says Holler. Meanwhile, scientists like Khemani remain cautious about the whole conversation surrounding quantum communication.Still, is it so wrong—and outside the realm of scientific possibility—for us to still want to bend time through some means other than time crystals?

Here's the good news: "Time travel cannot be excluded in principle," says Eltsov.

Now here's the slightly disappointing news: "But to understand it would require immense energy densities we are unable to produce in the lab either now or in the foreseeable future."

Think of the Large Hadron Collider (LHC) at CERN, the European Organization for Nuclear Research. The LHC, the world's largest and most powerful particle accelerator, **weighs over 38,000 tons**, runs for 27 kilometers in an underground tunnel, has particles guided by titanic superconducting magnets frenzying about it to speeds of 11,000 circuits per seconds, and cost about $4.8 billion. That's *really, really* massive—and we'd still need orders of magnitude beyond that to even look into time travel, Holler says. We're simply not ready.

"It's completely unfeasible with current technologies," says Curt von Keyserlingk, a theoretical physicist at the University of Birmingham, who contributed **additional theoretical work** with Khemani and Sondhi on time crystals in 2016. "But this does not mean it is impossible," he swiftly adds, prompting us to take a look at the work of physicist Kip S. Thorne.

Finding and Filling the Cracks

In 2017, Thorne **was awarded the Nobel Prize in Physics** alongside **Rainer Weiss** and Barry C. Barish for the first detection of a gravitational wave. Thorne is best known in the unforgiving world of physics as the originator of sci-fi friendly ideas. He's the one who **advised cosmologist and writer Carl Sagan** on resorting to a hypothetical traversable wormhole connecting two periods in time to transport Jodie Foster through the universe in *Contact,* the 1997 film based on Sagan's 1985 novel. He also **helped create a black hole** for *Interstellar* and **said that** wormholes could be used for space travel and time travel.

Thorne offered explanations for several logical conundrums regarding time travel, including the paradox of going back in time through a wormhole and accidentally killing your grandfather, thereby also killing yourself. (How can you exist if your father doesn't exist, since the sperm half responsible for his conception was destroyed … by you?) In **1991,** Thorne did some mathematical calculations and found that such paradoxes couldn't arise, but were instead replaced by an infinite number of other potential outcomes. (You could go back in time and mess around with your grandfather all you want, but there's no way you could have killed him, otherwise you wouldn't exist to kill him in the first place.)

Then there's the theory of the many worlds hypothesis, which could resolve some of the implications of going back in time and altering the future. This hypothesis suggests we live in a **near-infinity of universes** that have the same physical laws and values, but exist in different states and are arranged so that no information can pass between them. Essentially, with every decision we make, the universe splits into multiple realities, and we're completely unaware of the alternative scenarios our exact replicas experience in the other universes.

"Resolving the hardest problems in physics requires throwing away a lot of our preconceived notions."

"Time travel would, in the theory of multiverses, have us wind up on one of these other universes, so it would not necessarily be a straight linear path forward to back for us, but a crossing between universes," says Holler. "I'm not completely sold on it, but there are plenty of smart people working on it and seem to believe it's very, very feasible," he continues.

But the incredibly prepossessing theory of multiverses lacks proof in the form of solid calculations, says von Keyserlingk. For him, the problem with the many worlds interpretation and time travel isn't that they're necessarily fiction, but that we may currently be missing the mathematical tools and even philosophical ideas to negotiate these things. They're at the very theoretical end of physics, he says: things that we can really only speculate on, whereas science at its best is just "informed speculation."

"It can sometimes happen that nature presents us with issues that no one has figured out before," von Keyserlingk says. "One of the issues is that we have a fairly fixed idea of what space and time is. Resolving the hardest problems in physics requires throwing away a lot of our preconceived notions."

In a more mathematically, philosophically advanced future, then, could we discover more time-traveling properties of time crystals? Don't hold your breath, Khemani says. While the crystals do hold a few tiny secrets of the universe, the only thing they have in common with time travel is just one word: time. That's at least for now—but maybe not forever.

Some Scientists Believe the Universe Is Conscious

Sounds like a bad trip ... but what if it's true?

UPDATED: APR 05, 2022

Is the universe a conscious being, like a gigantic widely dispersed human brain? Scientists have long questioned how **consciousness** and science mix.

Two mathematicians have **turned one theory** into a crunchable math model.

In upcoming research, scientists will attempt to show the universe has consciousness. Yes, really. No matter the outcome, we'll soon learn more about what it means to be conscious—and which objects around us might have a mind of their own.

What will that mean for how we treat objects and the world around us? Buckle in, because things are about to get weird.

What Is Consciousness?

The basic definition of consciousness intentionally leaves a lot of questions unanswered. It's "the normal mental condition of the waking state of humans, characterized by the experience of perceptions, thoughts, feelings, awareness of the external world, and often in humans (but not necessarily in other animals) self-awareness," according to the **Oxford Dictionary of Psychology**.

Scientists simply don't have one unified theory of what consciousness is. We also don't know where it comes from, or what it's made of.

However, one loophole of this knowledge gap is that we can't exhaustively say other organisms, and even inanimate objects, *don't* have consciousness. Humans relate to animals and can imagine, say, dogs and cats have some amount of consciousness because we see their facial expressions and how they appear to make decisions. But just because we don't "relate to" rocks, the ocean, or the night sky, that isn't the same as proving those things don't have consciousness.

This is where a philosophical stance called *panpsychism* **comes into play**, writes *All About Space*'s David Crookes:"This claims consciousness is inherent in even the tiniest pieces of matter — an idea that suggests the fundamental building blocks of reality have conscious experience. Crucially, it implies consciousness could be found throughout the universe."

It's also where physics enters the picture. Some scientists have posited that the thing we think of as consciousness is *made of* micro-scale quantum physics events and other "spooky actions at a distance," somehow fluttering inside our brains and generating conscious thoughts.

The Free Will Conundrum

One of the leading minds in physics, 2020 Nobel laureate and **black hole** pioneer Roger Penrose, has written extensively about quantum mechanics as a suspected vehicle of consciousness. In 1989, he wrote a book called ***The Emperor's New Mind***, in which he **claimed** "that human consciousness is non-algorithmic and a product of quantum effects."

Let's quickly break down that statement. What does it mean for human consciousness to be "algorithmic"? Well, an **algorithm** is simply a series of predictable steps to reach an outcome, and in the study of philosophy, this idea plays a big part in questions about free will versus determinism.

Are our brains simply cranking out math-like processes that can be telescoped in advance? Or is something wild happening that allows us true free will, meaning the ability to make meaningfully different decisions that affect our lives?

Within philosophy itself, the study of free will dates back *at least* centuries. But the overlap with physics is much newer. And what Penrose claimed in *The Emperor's New Mind* is that consciousness isn't strictly causal because, on the tiniest level, it's a product of unpredictable quantum phenomena that don't conform to classical physics.

So, where does all that background information leave us? If you're scratching your head or having some uncomfortable thoughts, you're not alone. But these questions are essential to people who study philosophy and science, because the answers could change how we understand the entire universe around us.

Whether or not humans do or don't have free will has huge moral implications, for example. How do you punish criminals who could never have done differently?

Consciousness Is Everywhere

In physics, scientists could learn key things from a study of consciousness as a quantum effect. This is where we rejoin today's researchers: Johannes Kleiner, mathematician and theoretical physicist at the Munich Center For Mathematical Philosophy, and Sean Tull, mathematician at the University of Oxford.

Kleiner and Tull are following Penrose's example, in both his 1989 book and a 2014 paper where he detailed his belief that our brains' microprocesses can be used to model things about the whole universe. The resulting theory is called integrated information theory (IIT), and it's an abstract, "highly mathematical" form of the philosophy we've been reviewing.

In IIT, consciousness is everywhere, but it accumulates in places where it's needed to help glue together different related systems. This means the human body is jam-packed with a ton of systems that must interrelate, so there's a lot of consciousness (or *phi*, as the quantity is known in IIT) that can be calculated. Think about all the parts of the brain that work together to, for example, form a picture and sense memory of an apple in your mind's eye.

The revolutionary thing in IIT isn't related to the human brain—it's that consciousness isn't biological at all, but rather is simply this value, *phi*, that can be calculated if you know a lot about the complexity of what you're studying.

If your brain has almost countless interrelated systems, then the entire universe must have virtually infinite ones. And if that's where consciousness accumulates, then the universe must have a lot of *phi*.

Hey, we told you this was going to get weird.

"The theory consists of a very complicated algorithm that, when applied to a detailed mathematical description of a physical system, provides information about whether the system is conscious or not, and what it is conscious of," Kleiner **told *All About Space***. "If there is an isolated pair of particles floating around somewhere in space, they will have some rudimentary form of consciousness if they interact in the correct way."

Kleiner and Tull **are working on** turning IIT *into* this complex mathematical algorithm—setting down the standard that can then be used to examine how conscious things operate.

Think about the classic philosophical comment, “I think, therefore I am,” then imagine two geniuses turning that into a workable formula where you substitute in a hundred different number values and end up with your specific “I am” answer.

The next step is to actually crunch the numbers, and then to grapple with the moral implications of a hypothetically conscious universe. It’s an exciting time to be a philosopher—or a philosopher’s calculator.

Intelligent Aliens May Be All Across the Universe, a Controversial New Theory Suggests

According to an alternative model of how intelligent life emerges on planets like Earth, the existence of aliens—and human beings–could be the result of natural planetary processes.

PUBLISHED: FEB 20, 2025

Are we alone in the **universe**?

Probably not, say a group of scientists who believe there’s a good chance **aliens** are populating other planets outside our solar system. This idea is controversial because it flies in the face of a generally accepted 1983 hypothesis that says intelligent life on Earth is the unique outcome of a series of unlikely scenarios coalescing in just the right way—essentially, a sort of cosmic luck. Instead, the researchers say, the evolutionary processes that led to the creation of intelligent life forms, such as human beings, may have been a predictable outcome for not only us on our planet, but **extraterrestrial** life on other planets, too.

According to the broadly accepted “hard steps” model of intelligent evolution, which arose from theories in astrophysics, the likelihood of human life evolving rests on a bedrock of “hard steps.” At its core, this hypothesis says that, despite planetary life requiring a nearby star for energy, the amount of time it took humans to evolve on Earth, relative to the sun's total lifespan, means that our origin was unlikely. The hard steps model also predicts the apparent rarity of intelligent life in the universe.

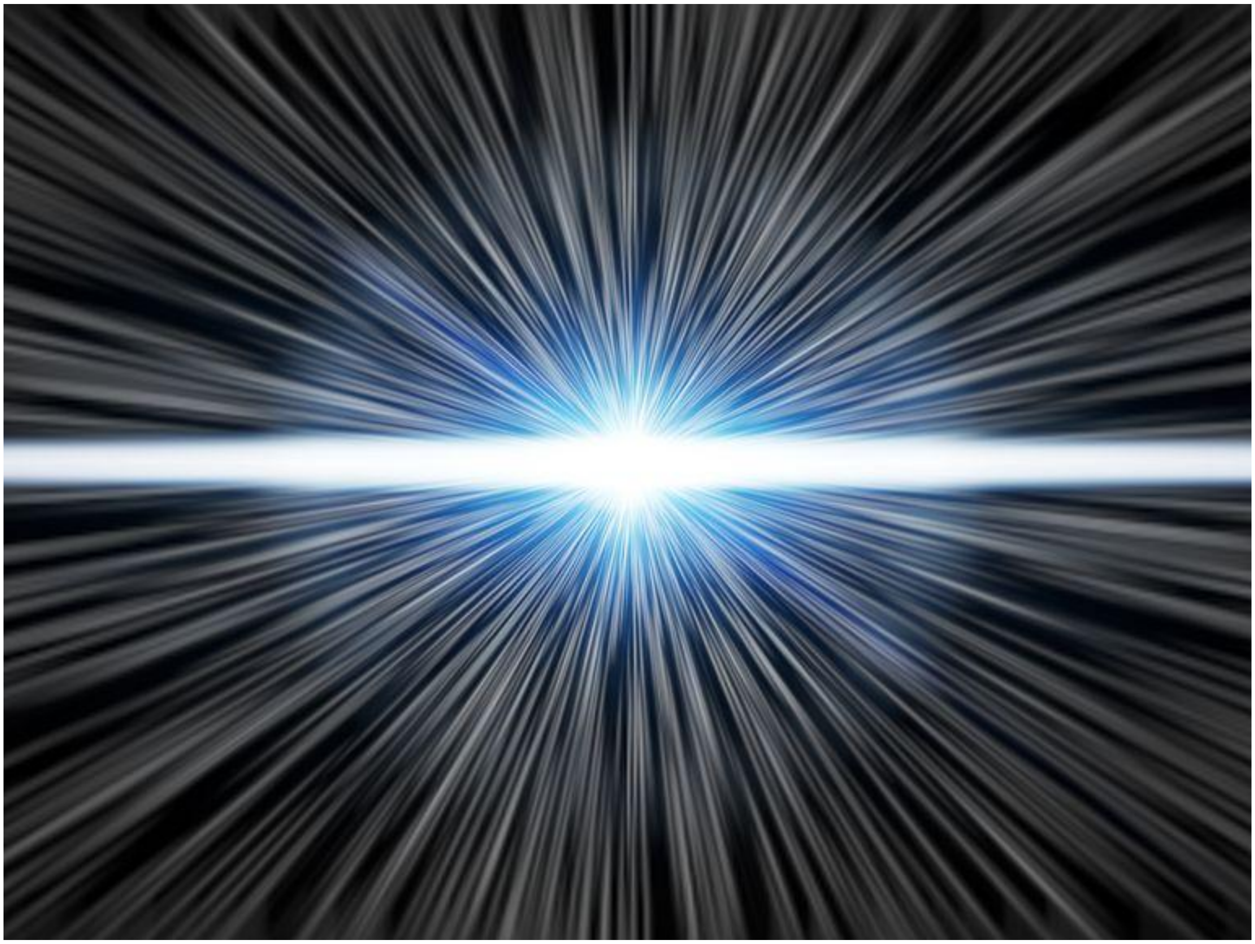
But researchers from Penn State University, the University of Munich in Germany, and the University of Rochester in New York published a study that overturns this idea. Their interdisciplinary model instead integrates knowledge from astrophysics, geoscience, paleontology, and biology to create a more comprehensive and nuanced view of how life emerges and evolves on a planet like Earth. The team published its **results** on February 14 in the journal *Science Advances*.

Rather than basing their study on the sun's lifespan, the researchers say our origins—and that of other intelligent life in the universe—could have been a natural outcome of our planet's changing environmental factors. These include drivers of life such as sea surface temperature, ocean salinity levels, and the amount of oxygen in the atmosphere. At various times in Earth's history, the confluence of multiple environmental factors open "windows" of opportunity for life to evolve and thrive, according to the study. This alternative model "suggests that the evolution of complex life may be less about luck and more about the interplay between life and its environment, opening up exciting new avenues of research in our quest to understand our origins and our place in the universe," Penn State geoscientist and paper co-author Jennifer Macalady, Ph.D., says in a press **release**.

In other words, human beings may not have needed "a series of lucky breaks" to be here today, says Dan Mills, Ph.D., a researcher at Ludwig Maximilian University of Munich and lead author on the paper. Humans arrived "at the right time" based on our planet's development, he says, "and maybe other planets are able to achieve these conditions more rapidly than Earth did, while other planets might take even longer."

The researchers plan to test their new model in several ways. For example, searching the atmospheres of planets outside our solar system could indicate biosignatures, like the presence of oxygen. This could indicate life forms that generate or consume oxygen. For example, on our planet, the large quantities of oxygen that led to multicellular life kicked off only after massive cyanobacteria populations emerged about 2.5 billion years ago and produced oxygen—and a similar process could be happening elsewhere. The scientists also want to test the hard steps model itself by placing unicellular and multicellular forms of life under challenging environmental conditions, such as lower oxygen and temperature levels, to see if they can cope. Perhaps the way these organisms respond could reveal that even the “hard steps” model of life is not that hard.

If not, it could be yet another argument in favor of life—perhaps even intelligent life such as humans—emerging multiple times across the universe.



This NASA Scientist Is Developing a Spacecraft for Interstellar Travel. Is It the Warp Drive We’ve Been Waiting For?

A scientific discovery that could transform the study of warp drive is now under wraps at the U.S. Defense Advanced Research Projects Agency.

Harold White, known to his friends as Sonny, was only 11 years old when the Smithsonian National Air and Space Museum was unveiled in his home city of Washington, D.C. in the summer of 1976. He and millions of other visitors explored the museum's halls to marvel at decades-old airplanes and space modules that had only just returned Earth-side, including the *Apollo 11*'s command module, *Columbia*. It had remained in orbit as Neil Armstrong and "Buzz" Aldrin became the first human beings to set foot on the moon. For White, visiting the museum became a pivotal moment that would ripple through his life and career as both a NASA scientist and dogged investigator of one of science's most challenging problems**:** how to reach the stars.

As an avid *Star Trek* fan and a kid who showed an aptitude for math, White says his path toward studying space may have been predetermined, but wandering the museum's halls helped stoke the flame. "This premise and the promise of space exploration for humanity just really always stuck with me," he says. After all, we still haven't sent people past the Moon, a cosmic stone's throw from home, and our fastest unmanned spacecraft, *Voyager 1*, will take 75,000 years to reach our nearest stellar neighbor, Proxima Centauri.

For White, the only solution that would extend the **exploration** of humanity beyond our solar system is to design a spacecraft that can travel the stars within a fraction of a human lifetime. In other words—**warp** drive.

Like many technologies White's beloved *Star Trek: The Original Series* in the 1960s predicted, such as the flip phones and wireless headsets, warp drive is a science fiction creation that has demonstrated surprising scientific validity.

In the television show, switching to **warp** drive is as easy as putting your car into a higher gear and allows the *U.S.S. Enterprise* to blink out of existence as it skips through space-time at speeds quicker than light. Captain Kirk and his crew still have a head start of more than 200 years on this technology, and today's warp drive science is still nowhere close to this ideal.

Here's the modern science of warp drive, in a nutshell. Physicist Miguel Alcubierre published the prevailing model of warp drive in 1994, and it shows that warp speed travel could theoretically be possible. However, we first need to manipulate Einstein's equations of general relativity using a type of exotic matter with negative energy. These equations essentially tell us that massive objects can distort space-time. A warp drive powered by this massive amount of energy would contort space-time into a bubble around the spacecraft, expanding space-time in front of the craft and compressing it behind. This warping would allow the craft itself to jump through **interstellar** space—without its passengers being any the wiser.

This idea has more than a few problems, chiefly that we've never observed this kind of negative energy source that Alcubierre predicts. But it's this problem that White has been trying to solve.

Since his museum days, White has come a long way in studying the underlying technology for humanity's race to interstellar space. When Alcubierre published his warp drive paper, it inspired White, who at the time was a young engineer at Boeing and pursuing his master's degree in mechanical engineering.

White would go on to earn a Ph.D. in physics from Rice University in Houston before a 16-year stint at NASA's Johnson Space Center, where he worked on advancing human spaceflight. Yet, while White was already doing his part to further our exploration of the stars, the idea that warp drive could revolutionize it never left his mind. In 2013 while still working at NASA, White gave **a presentation** called "Warp Field Mechanics 102: Energy Optimization" that modified Alcubierre's warp bubble to drastically reduce the amount of negative energy it required.

"By applying our optimization technique, we reduce the amount of exotic matter [required] from something the size of Jupiter to something about the size of the Voyager spacecraft," White says. *Voyager 1* is roughly the size of a compact car and weighs 733 kg.

Six-years later, White left NASA to become the director of advanced research and development at the newly founded Limitless Space Institute, whose goal is to "advance human exploration beyond our solar system” by researching both known physics, like nuclear powered propulsion, and unknown physics, like warp drive.

It was at the Limitless Space Institute in 2021, as part of ongoing work for the U.S. government’s Defense Advanced Research Projects Agency (DARPA), that White published **a paper** in the *European Physical Journal C* which showed that it was possible—though not yet experimentally proven—to develop a micro-scale warp bubble using a kind of quantum-level negative energy created by the Casimir effect.

Named after Dutch physicist, Hendrik Casimir, it describes a phenomenon that occurs when two uncharged but conducting metal plates are placed oppositely in a vacuum. The magnetic field surrounding them creates a negative force, which attracts them to each other. White and co-authors wrote in the paper’s abstract that this study suggests that “chip-scale” miniaturized experiments could be explored using the Casimir effect to develop “a real, albeit humble, warp bubble.”

Despite this splashy news and subsequent confusion that a real warp bubble had already been created, development on this work has been quiet over the last three years. White himself has said that he’s laser-focused on DARPA-funded work to explore Casimir cavities, the space between plates that creates the Casimir effect. in 2023 he became the CEO and founder of a nanotechnology company called Casimir that aims to“transform the energy landscape” by using nanotechnology that can interact with quantum fields.

So what does this mean for warp drive? At least for White, having no active projects in the works doesn’t mean that either he, or other researchers, are giving up.

Around the same time White published his warp bubble paper, a physicist in Germany published a **paper** in the journal Classical and Quantum Gravity which suggests there may be a warp drive solution that could do away with negative energy altogether. This idea has sparked interest in the scientific community but, as of yet, this model still brings us no closer to achieving true warp drive.

Yet despite it all, White has not lost hope in this dream for humanity. “I think the thing that really resonated with me when I was young [was] always the people's story — people working together to solve problems," White says, thinking back to his days at the National Air and Space Museum.

Comparing the study of warp drive to the long construction of a French cathedral in Strasbourg between 1015 and 1439, White says that it's possible he'll never see the final product of his warp drive research. Still, he's happy to contribute what he can so that one day it might be realized.

"I don't know when or if warp drive will be developed," White says, "But I know what I need to do next."

Warp Drives Are Possible and Aliens May Already Be Using Them, Scientists Say

If we track explosions from malfunctioning warp drives, we could finally discover where E.T.s are hiding.

BY JORDAN PEARSONPUBLISHED: JUL 16, 2024 3:16 PM EDT

Save Article

If a **warp drive** explodes in deep space, will anybody hear it? Probably not, but new research suggests that humans could one day detect the ripples in spacetime such a catastrophe would create, potentially aiding the search for alien life.

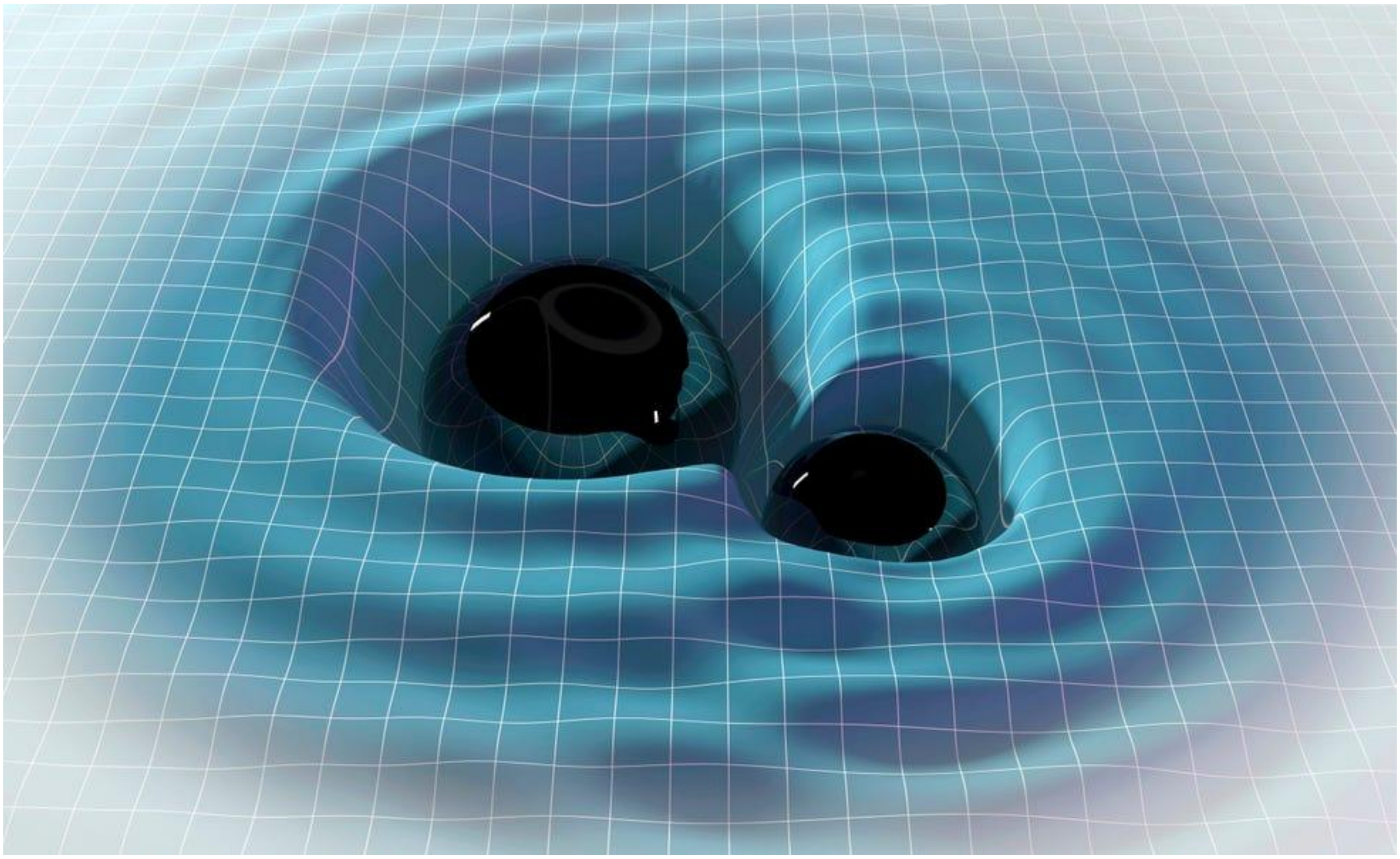
Warp drives that enable spacecraft to travel at near light speeds are a fixture of science fiction, famously allowing *Star Trek*'s Federation crews to boldly go where no one has gone before. But scientists have long theorized how a real-life warp drive might work, the most famous example being the **Alcubierre drive**, a design that Mexican physicist Miguel Alcubierre, Ph.D., put forth in 1994. This type of drive would form a bubble around travelers, contracting the space in front of it and expanding the space behind it to leap across the cosmos.

In a **preprint study** posted online in June, a team of researchers hailing from the U.K. and Germany posed the question: If an alien civilization is using an Alcubierre drive, could we detect it by looking for the gravitational waves such a system might emit? After all, the Pasadena, California-based LIGO Lab—home to the world's largest gravitational wave observatory—can pick up the perturbations in spacetime generated by highly energetic events like black hole mergers and supernovas.

So why not **alien technology**?

According to the researchers' calculations in this new work (which has not been peer-reviewed), humanity really *could* pick up on signs of an alien warp drive, but only with a new generation of gravitational wave observatories.

Warp Breach, Captain



Gravitational waves are very subtle. It takes extremely sensitive, precise instrumentation to detect the ripples that stretch and compress spacetime, a combination of time and three-dimensional space.

Astrophysicist Katy Clough, Ph.D., and her co-authors came up with the idea of simulating a warp drive's gravitational wave signature seven years ago. They were inspired by *Star Trek*, she says, and in particular by the occurrence of warp **"breaches"** in the show's universe.

An Alcubierre drive—which theoretically would require **negative energy** (a repulsive gravitational force, rather than an attractive one) and exotic forms of matter to work—wouldn't greatly perturb spacetime while operating correctly. Technically, even driving a car on Earth generates gravitational waves (anything that accelerates does), but they're too small to be detected or have much of an effect on anything. But the waves that reach our planet from space are typically caused by violent events or the movements of massive objects, like a spinning neutron star. A malfunctioning Alcubierre drive would qualify, too.

“If you put exotic matter into forming a warp bubble, it will naturally disperse over time. So, hypothetical aliens would need some kind of containment mechanism to keep it in place. And we don’t know what that is,” Clough explains. “We said, well, in *Star Trek*, it always happens that you have a warp-drive containment failure. So why don’t we just go with this idea?”

In a warp-drive containment breach, Clough says, all of the contained energy and matter would spill out and create the kind of messy oscillations that generate gravitational waves, like someone splashing around in a pool. This would be, to say the least, unpleasant for the ship’s occupants.

A warp-drive collapse in Andromeda—the nearest galactic neighbor to the Milky Way—could be detectable on Earth.

“You’d get stretched and squashed, and ultimately, it would be nasty,” Clough says.

Clough says the project seemed “fun” to the team at first, but that it quickly became very complicated. The main problem, Clough says, was choosing equations that both led to a stable evolution in the simulation *and* made physical sense.

That accomplished, Clough’s team found that a warp breach on a kilometer-sized ship traveling at 10 percent of the speed of light (30,000 kilometers per second), would create a “very distinct” gravitational wave signal. It could be detected from up to 1 megaparsec away, or 3.26 million light years, meaning a warp-drive collapse in Andromeda—the nearest galactic neighbor to the Milky Way—could be detectable on Earth.

Luke Sellers, Ph.D., lead scientist at Applied Physics—an independent research group based in New York City and Stockholm that has proposed **its own warp drive designs** and studied **the search for alien life** in gravitational wave signals—says the work from Clough’s team is a “welcome addition” to the field. The study “just makes sense,” he says, particularly the insight that an Alcubierre drive could blow apart.

One day, he said, “we could have a menu of all these exotic **SETI**-type gravitational wave signals” to look for, “one of which might be a very large propulsive mechanism, and one of which could be this warp drive explosion.”

The Next Generation

Assuming that aliens have figured out how to make an Alcubierre drive and one explodes within range of our observatories, there's still a problem: none of our existing detectors are equipped to pick up high-frequency gravitational waves.

Gravitational wave detection is still "a really new field," Clough says. "It's really like the beginning of electromagnetic observations, where we're just looking at one frequency band."

Caltech and MIT's ground-based LIGO observatory, for example, debuted in 2002 and **eavesdrops on frequencies** in the range of 10 Hz to 1 KHz. (If a 1-KHz wave was sonified, it would sound like **a high-pitched whining tone**.) NASA and the European Space Agency's planned space-based LISA observatory, which is expected to launch in the 2030s, will listen in on even lower ranges. An exploding Alcubierre drive would emanate waves at a frequency of about 300 KHz, which, if it was a sound, would be outside the range of human hearing.

The reason for this initial focus on lower frequency bands, Clough says, is that there are high-priority objects and events in those ranges.

"There aren't that many well-motivated astrophysical targets at those kinds of [higher] frequencies," she explains. "There are some exotic things, like **primordial black holes** or signals from the early universe, so there are proposals to try and build detectors in that range. This is another potential argument for building those detectors."

Indeed, in 2021, a team of over two dozen scientists from around the world, including institutions like LIGO and CERN, **argued in a paper** that observatories targeting high frequency ranges would allow us to look for signs of novel physics in the early universe, for example.

"It stands to reason that you want to probe that vastness as much as possible, if you want to have a chance to detect something," says Sellers, the scientist from Applied Physics. On top of new detectors, a "pipeline" for SETI searches involving machine learning algorithms could be beneficial, he says.

The paper's conclusions also come with some caveats. The work covers a very specific scenario with carefully chosen parameters, including the type of warp drive. It's "an example, and not the template to look for," Clough says. Still, her team expects that the frequency range of the gravitational waves would carry over to other designs.

"It could be the case that, once we get these better detectors, there's a really loud warp drive signal that you can see even if you didn't already know what you're looking for," Sellers says. "And if that happens, it's conceivable that we could actually reverse engineer what system they're using."

By Harnessing the Unlimited Vacuum Energy In Space, We Could Finally Reach Light Speed

Invisible vacuum energy is all around us. We could use it to power propulsion, enhance nanostructures, and build levitating devices.

PUBLISHED: MAR 29, 2024

Hendrik Casimir's idea for an experiment was simple: bring two metallic objects extremely close together and wait. Spontaneously, as if by magic, the objects will be drawn together. No external forces, no pushes or pulls, no action of gravity or tension or **magnetism**. The objects simply get closer. The reason? An unlimited source of vibration sitting in the very vacuum of spacetime.

This landmark experiment, first devised by Casimir just after World War II—and only realized 25 years ago—paved the way for scientists to witness the manifestations of quantum theory in a real, practical way. Quantum fields and their vibrations power our modern-day understanding of physics, from subatomic interactions to the evolution of the entire universe. And what we learned, thanks to Casimir's work, is that infinite energy permeates the vacuum of space. There are many ideas in the science fiction universe that propose using vacuum energy to **power a starship** or other advanced kind of propulsion, like a warp drive. While these ideas are still dreams, the fact remains that a simple experiment, devised in 1948, set fire to our imaginations and our understanding of the universe.

Casimir, a Dutch physicist, had spent his graduate years with his advisor, Niels Bohr, one of the godfathers of **quantum physics**, and had picked up a liking for this new, extraordinary theory of the cosmos. But as quantum theory evolved, it started to make extremely strange statements about the **universe**. The **quantum world is weird**, and its ultimate weirdness is normally invisible to us, operating at scales well below our normal human perception or experimentation. Casimir started to wonder how we might be able to test those ideas.

He went on to discover a clever way to measure the effects of ever-present infinite quantum fields merely using bits of metal held extremely close together. His work showed that quantum behavior can manifest in surprising ways that we can measure. It also showed that the strangeness of quantum behavior is real and can't be ignored, and what quantum mechanics says about the **workings of the universe**—no matter how bizarre—must be believed.

Quantum Fields Are Otherworldly, But Very Real

One of the lessons of the quantum world is that **particles**, like electrons, photons, neutrinos, and whatnot, aren't what they seem to be. Instead, each of the particles that we see in nature is actually just a piece of a much larger, grander entity. These grander entities are known as quantum fields, and the fields soak every bit of space and time—all throughout the universe—the same way that oil and vinegar soaks a piece of bread.

There is a quantum field for every kind of particle: one field for the **electrons**, one for the photons, and so on. These fields are invisible to us, but they make up the fundamental building blocks of existence. They are constantly vibrating and buzzing. When the fields vibrate with enough energy, **particles** appear. When the fields die down, the particles disappear. Another way to look at this is to say that what we call a "particle" is really a localized vibration of a quantum field. When two particles interact, it's really just two pieces of quantum fields interacting with each other.

There's no such thing as a true vacuum; wherever you go, there are always vibrating quantum fields.

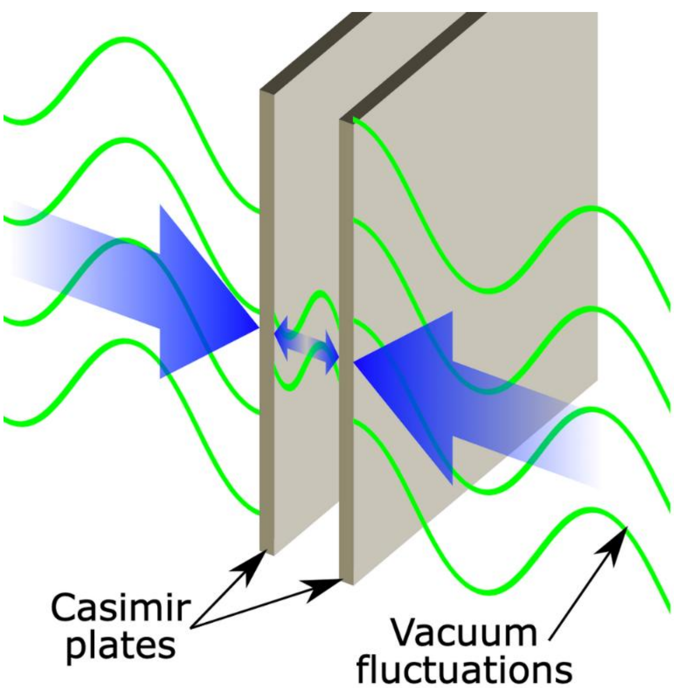
These quantum fields are always vibrating, even when those vibrations aren't strong enough to produce a particle. If you take a box and empty out all of the stuff—all the electrons, all the photons, all the neutrinos, all the everything—the box is still filled with these quantum fields. Since those fields vibrate even in isolation, that means the box is filled with invisible vacuum energy, also known as zero-point energy—the energy of these fundamental vibrations.

In fact, you can calculate how many vibrations are in each of these quantum fields ... and the answer is infinity! There are small ones, medium ones, big ones, and gigantic ones, all flopping on top of each other continuously, as if spacetime itself was boiling at the subatomic level. This means that the vacuum of the universe really is made of something. There's no such thing as a true vacuum; wherever you go, there are always vibrating quantum fields.

A Simple Experiment Involves Multiple Infinities

This is where Casimir's experiment comes in: If you take two metal plates and stick them really, really close together, the quantum fields between those plates must behave in a certain way: the wavelengths of their vibrations must fit perfectly between the plates, just like the vibrations on a guitar string have to fit their wavelengths to the length of the string. In the quantum case, there are still an infinite number of vibrations between the plates, but—and this is crucial—there are not *as many* infinite vibrations between the plates as there are outside the plates.

How does this make sense? In mathematics, not all infinities are the same, and we've developed clever tools to be able to compare them. For example, consider one kind of infinity where you add successive numbers to each other. You start with 1, then add 2, then add 3, then add 4, and so on. If you keep that addition going forever, you'll reach infinity. Now consider another kind of addition, this one involving powers of 10. You start with 101, then add to it 102, then 103, then 104, and keep going.



Casimir's experiment brings two metallic objects extremely close together. The objects will be drawn together because of vibrations in the quantum field and no other force.

Again, if you keep this series going on forever, you'll also reach infinity. But in a sense you'll "get" to infinity faster. So by carefully subtracting these two sequences, you can get a measure of their difference even though they both go to infinity.

Using this clever bit of mathematics, we can subtract the two kinds of infinities—the ones between the metal plates and the ones outside—and arrive at a finite number. This means that there really are more quantum vibrations outside the two plates than there are inside the plates. This phenomenon leads to the conclusion that the quantum fields outside the plates push the two plates together, something called the Casimir effect in Hendrik's honor.

The effect is incredibly small, roughly 10^{-12} Newtons, and it requires the metal plates to be within a micrometer of each other. (One Newton is the force which accelerates an object of 1 kilogram by 1 meter per second squared.) So, even though Casimir could predict the existence of this quantum effect, it wasn't until 1997 that we were finally able to measure it, thanks to the efforts of Yale physicist Steve Lamoreaux.In this experimental setup, which can fit on a kitchen countertop, the plates don't magically pull themselves together. Instead it's the infinite vibrating quantum fields of spacetime pushing them together from the outside.

We don't normally see or sense or experience the Casimir effect. But when we want to **design micro- and nano-scale machines**, we have to account for these additional forces. For example, researchers have designed micro-scale sensors that can monitor the flow of chemicals on a molecule-by-molecule basis, but the Casimir effect can disrupt the operations of this sensor if we didn't know about it.

Scientists Are Exploring the Potential of Vacuum Energy

For several years, researchers have been investigating the possibility that we really can extract vacuum energy and use it for energy. A **2002 patent** was awarded for a device that captures the electric charge from the Casimir experimental setup's two metal plates, charging a storage battery. The device can be used as a generator. "To continuously generate power a plurality of metal plates are fixed around a core and rotated like a gyrocompass," according to the patent.

The U.S. Defense Department's Defense Advanced Research Projects Agency (DARPA) **gave researchers $10 million in 2009** to pursue a better understanding of the Casimir force. Though progress in actually using vacuum energy continues to be incremental, this line of energy research could give rise to innovations in nanotechnology, such as building a device capable of levitation, researchers said at the time.

At the University of Colorado in Boulder, **Garret Moddel**'s research group has developed devices that produce power "that appears to result from zero-point energy quantum fluctuations," according to the **group's website**. Their device essentially recreates Casimir's experiment, generating an electrical current between the two metal layers that researchers could measure, despite applying no electrical voltage.

As for Casimir himself, who was immersed in a quantum revolution unfolding at Leiden University, he had a tendency to downplay the importance of his own work. In his autobiography, ***Haphazard Reality***, Casimir said, "The story of my own life is of no particular interest." And his monumental 1948 paper designing his experiment ends with the simple statement, "Although the effect is small, an experimental confirmation seems not infeasable and might be of a certain interest."

In fact, his initial insight did not make a big splash on the scientific community, nor were there glowing popular press accounts of his experiment. Part of the reason was Casimir's own modesty, and another is that he soon left academic research to pursue a career in industry. But despite these humble beginnings, his work cannot be understated.

Today, we **continue to refine** Casimir's original experimental setup, searching for any cracks in our theories, and we use it as a foundation to explore ever more deeply the fundamental nature of the cosmos.

A Groundbreaking Scientific Discovery Just Gave Humanity the Keys to Interstellar Travel

In a first, this warp drive actually obeys the laws of physics.

PUBLISHED: MAY 29, 2024

With the ease of starting a car, the crew of the USS *Enterprise* starship streaks to a new adventure in every episode of *Star Trek*, somehow traveling at several times the **speed of light**. This sci-fi mode of practical interstellar travel, which television audiences first saw in 1966, inspired Mexican physicist Miguel Alcubierre Moya to investigate the feasibility of a real method for light-speed propulsion. Decades later, he published his cutting-edge research to an astonished community of theoretical physicists. The eponymous **Alcubierre warp drive** hypothetically contracts the spacetime in front of a spaceship while expanding the spacetime behind it, so that the ship moves from Point A to Point B at an "arbitrarily fast" speed. By distorting spacetime—the continuum enfolding the three dimensions of space and time—an observer outside the ship's "warp bubble" would see the ship moving faster than the speed of light, even though observers inside the craft would feel no acceleration forces.

If a superluminal—meaning faster than the speed of light—warp drive like Alcubierre's worked, it would revolutionize humanity's endeavors across the **universe**, allowing us, perhaps, to reach Alpha Centauri, our closest star system, in days or weeks even though it's four light years away.

However, the Alcubierre drive has a glaring problem: the force behind its operation, called "negative energy," involves exotic particles—hypothetical matter that, as far as we know, doesn't exist in our universe. Described only in mathematical terms, exotic particles act in unexpected ways, like having negative mass and working in opposition to gravity (in fact, it has "anti-gravity"). For the past 30 years, scientists have been publishing research that chips away at the inherent hurdles to light speed revealed in Alcubierre's foundational 1994 article **published in the peer-reviewed journal *Classical and Quantum Gravity***.

Now, researchers at the New York City-based think tank **Applied Physics** believe they've found a creative new approach to solving the warp drive's fundamental roadblock. Along with colleagues from other institutions, the team envisioned a "positive energy" system that *doesn't* violate the known **laws of physics**. It's a game-changer, say two of the study's authors: Gianni Martire, CEO of Applied Physics, and Jared Fuchs, Ph.D., a senior scientist there. Their work, also **published in *Classical and Quantum Gravity*** in late April, could be the first chapter in the manual for interstellar spaceflight.

POSITIVE ENERGY MAKES all the difference. Imagine you are an astronaut in space, pushing a tennis ball away from you. Instead of moving away, the ball pushes back, to the point that it would "take your hand off" if you applied enough pushing force, Martire tells *Popular Mechanics*. That's a sign of negative energy, and, though the Alcubierre drive design requires it, there's no way to harness it.

Instead, regular old positive energy is more feasible for constructing the "**warp bubble**." As its name suggests, it's a spherical structure that surrounds and encloses space for a passenger ship using a shell of regular—but incredibly dense—matter. The bubble propels the spaceship using the powerful gravity of the shell, but without causing the passengers to feel any acceleration. "An elevator ride would be more eventful," Martire says.

That's because the density of the shell, as well as the pressure it exerts on the interior, is controlled carefully, Fuchs tells *Popular Mechanics*. Nothing can travel faster than the speed of light, according to the gravity-bound principles of Albert Einstein's theory of **general relativity**. So the bubble is designed such that observers within their local spacetime environment—inside the bubble—experience normal movement in time. Simultaneously, the bubble itself compresses the spacetime in front of the ship and expands it behind the ship, ferrying itself and the contained craft incredibly fast. The walls of the bubble generate the necessary momentum, akin to the momentum of balls rolling, Fuchs explains. "It's the movement of the matter in the walls that actually creates the effect for passengers on the inside."

Building on its **2021 paper** published in *Classical and Quantum Gravity*—which details the same researchers' earlier work on physical warp drives—the team was able to model the complexity of the system using its own computational program, Warp Factory. This toolkit for modeling warp drive spacetimes allows researchers **to evaluate Einstein's field equations** and compute the energy conditions required for various warp drive geometries.

Anyone can **download and use it for free**. These experiments led to what Fuchs calls a mini model, the first general model of a positive-energy warp drive. Their past work also demonstrated that the amount of energy a warp bubble requires depends on the shape of the bubble; for example, the flatter the bubble in the direction of travel, the less energy it needs.

THIS LATEST ADVANCEMENT suggests fresh possibilities for studying warp travel design, Erik Lentz, Ph.D., tells *Popular Mechanics*. In his current position as a staff physicist at Pacific Northwest National Laboratory in Richland, Washington, Lentz contributes to research on dark matter detection and quantum information science research. His independent research in **warp drive theory** also aims to be grounded in conventional physics while reimagining the shape of warped space. The topic needs to overcome many practical hurdles, he says.

Controlling warp bubbles requires a great deal of coordination because they involve enormous amounts of matter and energy to keep the passengers safe and with a similar passage of time as the destination. “We could just as well engineer spacetime where time passes much differently inside [the passenger compartment] than outside. We could miss our appointment at Proxima Centauri if we aren’t careful,” Lentz says. “That is still a risk if we are traveling less than the speed of light.” Communication between people inside the bubble and outside could also become distorted as it passes through the curvature of warped space, he adds.While Applied Physics’ current solution requires a warp drive that travels below the speed of light, the model still needs to plug in a mass equivalent to about two Jupiters. Otherwise, it will never achieve the gravitational force and momentum high enough to cause a meaningful warp effect. But no one knows what the source of this mass could be—not yet, at least. Some research suggests that if we could somehow harness **dark matter**, we could use it for light-speed travel, but Fuchs and Martire are doubtful, since it’s currently a big mystery (and an exotic particle).

Despite the many problems scientists still need to solve to build a working warp drive, the Applied Physics team claims its model should eventually get closer to light speed. And even if a feasible model remains below the speed of light, it’s a vast improvement over today’s technology. For example, traveling at even half the speed of light to Alpha Centauri would take nine years. In stark contrast, our fastest spacecraft, Voyager 1—currently traveling at 38,000 miles per hour—would take 75,000 years to reach our closest neighboring star system.

Of course, as you approach the actual speed of light, things get truly weird, according to the principles of **Einstein's special relativity**. The mass of an object moving faster and faster would increase infinitely, eventually requiring an infinite amount of energy to maintain its speed.

"That's the chief limitation and key challenge we have to overcome—how can we have all this matter in our [bubble], but not at such a scale that we can never even put it together?" Martire says. It's possible the answer lies in condensed matter physics, he adds. This branch of physics deals particularly with the forces between atoms and electrons in matter. It has already proven fundamental to several of our current technologies, such as transistors, solid-state lasers, and magnetic storage media.

The other big issue is that current models allow a stable warp bubble, but only for a constant velocity. Scientists still need to figure out how to design an initial acceleration. On the other end of the journey, how will the ship slow down and stop? "It's like trying to grasp the automobile for the first time," Martire says. "We don't have an engine just yet, but we see the light at the end of the tunnel." Warp drive technology is at the stage of 1882 car technology, he says: when automobile travel was possible, but it still looked like a hard, hard problem.

The Applied Physics team believes future innovations in warp travel are inevitable. The general positive energy model is a first step. Besides, you don't need to zoom at light speed to achieve distances that today are just a dream, Martire says. "Humanity is officially, mathematically, on an interstellar track."

Consciousness Isn't Just in Your Head—It May Be Altering Reality Itself, Scientists Say

Ever since we published our very first issue 123 years ago—yes, we're old—*Popular Mechanics* has endeavored to help you understand all kinds of technological marvels, from the tools in your shed, to the planes in the sky, to the tanks on the battlefield. But lately, we've really tried to dive deep into the world's most complex machine: you.

Or, more specifically, the thing that makes you *you*: **consciousness**.

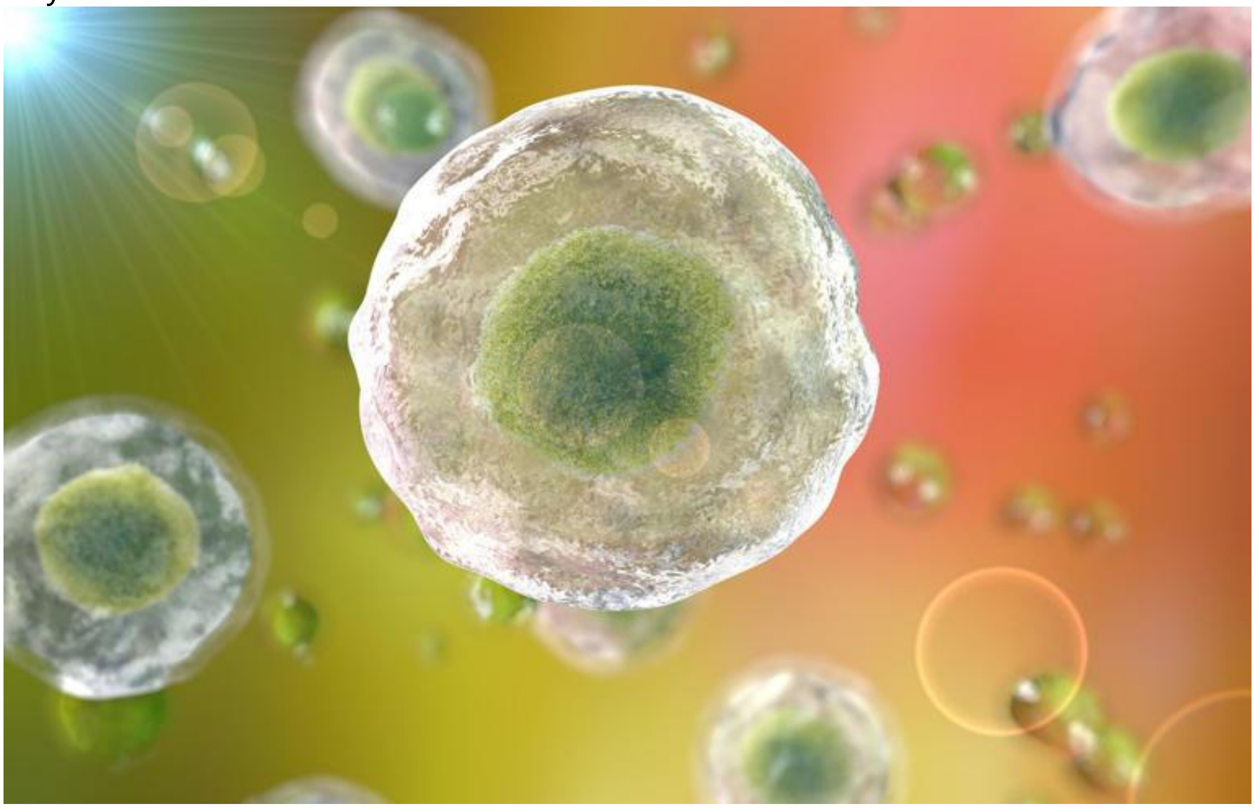
The question of, "What is consciousness?" is no longer exclusively the realm of ancient philosophers and dorm-room debaters. In the last few years, scientists across all kinds of disciplines have been making remarkable breakthroughs in the study and exploration of consciousness—and *PopMech* has been along for the ride every step of the way.

We've covered every piece of cutting-edge research that could redefine our entire understanding of ourselves and the world around us. In the process, we've had to ask some mind-bending questions like:

- ***Does consciousness stretch beyond the boundary of our brains?***
- ***Do we ever really die?***
- ***And does consciousness affect only our perception of reality, or can it actually reshape reality *itself*?***

Are Your Cells Conscious?

Is consciousness confined to your brain, or does every part of your body contain a kind of consciousness, down to the cellular level? That's what William B. Miller, Ph.D., an evolutionary biologist and physician, is trying to figure out. Miller and his team have proposed ideas that flip Charles Darwin's concept of natural selection on its head, including how consciousness may play a critical part in the way life evolves.



Miller is among a small, but growing group of scientists who believe that your cells aren't "passive robots that automatically follow a code of instructions, carrying out orders from our genome like mindless drones." Instead, these scientists think the roughly 37 trillion cells that make up your body are *themselves* conscious—and that life and consciousness began exactly at the same time.

This concept of cellular consciousness has gained further credence with the advent of a new class of AI-designed multicellular organisms known as "xenobots." These are cells that form new roles beyond their original biological function, such as using hairlike cilia for locomotion rather than transporting mucus. This is why scientists like Peter Noble, Ph.D., and Alex Pozhitkov, Ph.D., say that xenobots form a kind of "third state" of life, "wherein cells can reorganize after the death of an organism to form something new."

Xenobots, then, could radically alter our understanding of life, where the conscious cell—and *not* the organism—is the "fundamental unit of biological agency."

Here's the astonishing truth about these conscious cells, and why they're the next great leap in science.

Scientists aren't just exploring consciousness in our bodies—they're also searching for it in even weirder, more complex places.

In recent decades, some experts have developed a theory that says when your brain performs quantum operations, it generates consciousness. One scientist, Michael Pravica, Ph.D., for example, believes that your brain can access hidden dimensions during moments of heightened awareness. (You *have* to read his explanation for **what happens during a "Eureka" moment**.)

Does Consciousness Exist in the Quantum Realm?

We once asked a theoretical physicist, an experimental physicist, and a philosophy professor to weigh in on the controversial concept—sounds like the setup to a joke—and they couldn't come to a consensus on a direct connection between quantum mechanics and consciousness... yet.

But these ideas don't have to be purely theoretical; to some degree, they can be put to the test. That was the case with a recent groundbreaking study that suggests **Your Consciousness Can Connect With the Whole Universe**.

In the study, scientists administered anesthesia to rats, some of whom also received molecules that stabilized a microscopic part of their brain known as "microtubules," or hollow tubes that experts believe "perform incredible operations in the quantum realm." The stabilized rats actually remained conscious for longer, suggesting a tantalizing link between these quantum brain components and the very essence of consciousness itself.

Do Psychedelics Enhance Consciousness?

If this all sounds trippy, you're right—and, as it turns out, taking "trips" on psychedelics might actually unlock new levels of consciousness.

In a study from Johns Hopkins' Center for Psychedelic and Consciousness Research, people who used substances like LSD and DMT reported experiencing a connection to an "ultimate reality" and "had a decreased fear of death." (And here's why some psychedelics even allow some users to "see God.")

But let's go a step further: What if psychedelics like magic mushrooms aren't just a new way to expand your consciousness? What if they're *the very thing that helped shape it*?

A research review from the Miguel Lillo Foundation in Argentina concluded that, "psilocybin not only influenced an individual's perceptions while under its effects, but shaped human consciousness as a whole over the thousands of generations that humans had been eating psychedelic fungi."

We know—that's a *lot* to take in. And yet, it's just the beginning. Consciousness remains one of the most profound, mind-blowing mysteries in all of science, and we've covered its every twist and turn, including:

- ***Could consciousness be electromagnetic?***
- ***Will alien consciousness be different than our own?***
- ***Can we merge our consciousness with machines?***

Every day, scientists all over the world are continuing to dive deeper into what makes us who we are. From radical new research to the daring pursuits that push the limits of understanding, there's always more to learn.

Neuroscientists have observed for the first time how structures deep in the brain are activated when the brain becomes aware of its own thoughts, known as conscious perception.

Consciousness Isn't Made In The Brain, It's Being Channeled: A Theoretical Physicist Calls For "Scientific-Spirituality"

DR. JASON YUAN MARCH 29, 2025

Growing up, schools taught us that it's the electrical activity in our brains is what makes us conscious, sentient beings. But what if that is completely backward?

Emerging theories out of theoretical physics and complexity science are beginning to paint a very, very familiar picture. A picture that ancient spiritual practices have long taught: **consciousness is the source of physical reality and everything in between.**

One of these trailblazing theories comes from theoretical physicist Dr. James Glattfelder, whose interview with the Asencia Foundation attempts to do the once-thought impossible: **bridge grounded science with mystical spirituality**.

A Whole New [Scientific] World?

Conventional science has long run into the dead-end alley of what's called the "hard problem of consciousness". Simply put, current physics and biology cannot explain **qualia** or how subjective experiences can originate from brain neurons firing.

This challenge has ignited many scientists to call for a new age of **post-materialism**, arguing for a revolution of the scientific method to include consciousness and subjective experiences as part of our process of understanding reality. Emerging research in the fields of information theory and psychedelic studies continues to build momentum for this cause.

Transitioning into this new post-materialist world, Glattfelder argues for one principle that unites us all: **consciousness itself underlies the nature of reality and exists in a universal field throughout the cosmos**.

He states that **the brain does not generate consciousness; rather, the brain picks up consciousness from this universal field like a radio signal and transmits it.**

A Co-Creating Reality?

The term "co-creating reality", where an individual's thoughts and actions affect everyone else, has often been ridiculed by rationalists for its new-age spiritual roots and lack of credibility.

But Glattfelder ties it back to physicist John Wheeler's theory called the "**participatory universe**" where reality does not exist in a definitive state until it has been observed [by consciousness].

He cites that quantum realms do not function logically or predictably. Rather, it behaves like a field with infinite potential and only "collaspses" into a measurable, defined state through conscious observation.

This theory parallels with the **wave-function collapse**, which essentially states that until you look to measure a particle, it is not in one place - it's in a superposition of all possible places.

A "Fringe" Science Idea?

While mainstream physicists scoff at the idea that consciousness has a role in collapsing the wave function, the truth is more nuanced. The **measurement problem** - the unresolved puzzle of why and how quantum possibilities reduce to one actual outcome - remains one of the deepest mysteries in physics.

Acclaimed scientists like Eugene Wigner and Roger Penrose have proposed that **consciousness may be fundamental** to this measurement problem process.

In this view, Glattfelder integrates the participatory model of reality - **one where observation doesn't just reveal the world but helps *create* it. Consciousness becomes primary, and matter is secondary.**

While this doesn't mean every thought magically alters the universe, as some New Age interpretations claim. Rather, it suggests that at the most foundational level, reality and consciousness are intertwined.

A Universal Computer Program?

The idea of a universal program that generates multiple realities has been entertained in films such as The Matrix.

Instead of Hollywood scripts, Glattfelder draws evidence from computational theory and complexity science to suggest this: **The universe may be a software program, encoded by simple universal laws, that generates infinite realities and complex behaviors.**

In this view, the Newtonian aspects of space and time are not vital and rather, they are superficial properties of a deeper computational process of this program. Space and time may appear to be real on its surface, but it's merely information woven together by complex algorithms of entanglement of quantum fields.

To put it practically, our physical world may be just the symptom of a deeper information-driven cosmos where consciousness acts in between the "created" and the "creator".

Science with Spirituality?

Against typical norms, Glattfelder draws connections between modern science and the insights of mystical practices.

Science has long dismissed the subjective experiences of people undergoing miraculous, spiritual experiences. Whether that be spontaneous healings, outer body experiences, and other parapsychological phenomena. Why? Because conventional science cannot explain them. But that does not mean that these anecdotal evidence hold no value.

Through these deeper states of consciousness - whether reached through meditation, shamanic trance, or psychedelics - people of all faiths and ethnicities have universally claimed one major theme: **Everything in the universe is connected by an omniscient intelligence that the mind can access beyond space and time.**

This universal theme of the one consciousness is taught in spiritual traditions such as:

- **Christianity**
    - *"In the beginning was the Word, and the Word was with God, and the Word was God. He was with God in the beginning. Through Him all things were made; without Him nothing was made that has been made."* **-** *John 1:1–3*
- **Vedanta (Hinduism)**

    - *“He sees all beings in the Self, and the Self in all beings; he does not hate anyone.” - Bhagavad Gita 6:29*
- **Sufism**
    - *“I was a hidden treasure, and I loved to be known. So I created the creation, that I might be known.” - Hadith Quds*
- **Kabbalah**
    - *“He is the Know-er, the Object of Knowledge, and the Knowledge itself. Everything that exists emanates from Him and returns to Him.” - Book of Creation*
- **Taoism**
    - *“There is a thing confusedly formed, born before heaven and earth. Silent and void it stands alone, unchanging. It is ever present and never weary. It is the mother of all things under heaven.” - Tao Te Ching*
- **Buddhism**
    - *“All phenomena are like a dream, an illusion, a bubble, a shadow… so should one view them.” — Diamond Sutra*

Glattfelder argues that all experiences should be acknowledged as valid. This is where science can not only validate biophysical equations for neural activity of consciousness but also give grounded meaning to ALL spiritual practices and their views on reality.

As Glattfelder eloquently states, “We need a modern version of idealism — a scientific spirituality — to bring meaning back into our worldview.”

Consciousness and the Biofield: Post-Materialist World of Healthcare

This broader movement in post-materialist science has profound implications for the field of **biofield science** — an emerging discipline exploring how this invisible field of energy and information influences our health, **all of which is directed by consciousness**.

Mounting evidence for biofield therapies, such as Reiki, demonstrates that these practices can generate positive health outcomes that are distinct from and better than placebo (Zadro 2022).

So, if consciousness truly underlies reality, then these biofield therapies may represent some of the most direct ways we can tap into this foundational fabric of existence for healing purposes.

If this is the case, biofield science may be one of the most important frontiers in the post-materialist world of healthcare.

So What's the Takeaway?

If consciousness is fundamental, then every thought, feeling, and intention carries weight in our cosmos. You are not a spontaneous accident of scientific laws; rather, you, a conscious sentient being, stand as the bridge between the realities of what's possible and what's impossible.

With this Scientific-Spiritual view on life, Glattfield inspires us to look for a deeper sense of responsibility for understanding our planet, our fellow beings, and the mystery of existence itself.

Relationship between science and spirituality

Scientific spirituality is a term that refers to the **relationship between science and spirituality**. While science exists to uncover spiritual truths, those engaged in spirituality are interested in the scientific laws of nature but wish to go behind the laws to find the divine law that brought everything into being. Scientific spirituality seeks to explain how science and spirituality work together.

Science of Spirituality**+1**

Consciousness Doesn’t Come From Matter - Matter Comes From Consciousness": Breaking Down A Former-CERN Scientist's Theory

DR. JASON YUAN
APR 05, 2025

Conventional science teaches us that our biological hardware is what produces consciousness. The electrical circuitry of brain neurons is what spontaneously creates our understanding of thoughts and emotions to our environment. Many would believe that our universe is inherently physical - bound by universal mathematical laws that can explain everything.

But as we are learning now in quantum and theoretical physics, truth can be dynamic. Different truths can apply (or not apply) at different levels. And Bernardo Kastrup, a former CERN scientist, argues for an all-encompassing truth.

He calls it **Analytic Idealism**, a dynamic theory that asserts: **consciousness doesn’t come from matter - matter comes from consciousness.**

Are You Out Of Your [Mind]?

Krastrup claims that “All [physical] matter is what mind looks like from the outside.”

This statement revolves around how conventional science cannot explain **qualia** or one's internal experience of sense perceptions arising from stimulation of our external senses. To address this problem, Krastrup's model states that your subjective thoughts and emotions aren't a byproduct of the brain's neurons firing. The brain and physical reality itself is what your consciousness appears to be from the outside, a.k.a "**matter is the outward appearance of mental states.**"

Here's an analogy. When a person is smiling, the physical appearance of the smile doesn't cause happiness. Smiling is a symptom of happiness. Therefore, a person's brain activity doesn't cause consciousness - the brain activity is also a symptom or condition of consciousness.

> He emphasizes that "**the brain is what your conscious inner life looks like to someone else—a third-person dashboard view of a first-person experience.**"

Mind at Large: The Big "C" in Consciousness

Tieing everything together is what Kastrup calls the **Mind at Large**, where everything connects back to the one universal source of consciousness.

The analogy I like to use is akin to the ocean. The ocean is a collective body of water that produces an infinite number of individual waves on its surface. Our individual human experience is like a singular wave. Above the ocean's surface, each wave experiences separation from the whole, but only temporarily.

This brings us to the topic of death, which Kastrup calls an illusion. When the physical body dies, it's like our individual waves crashing back into the ocean. This is where the merging of our little "c" consciousness back with the big "C" consciousness as its source.

Aligning with physicist Federico Faggin's views, this means that you're not a biological machine that became aware - you come from a larger awareness that built this biological machine.

Bridging the Gap

If Analystical Idealism holds up, it means:

- You’re not a byproduct of matter - you are, and originate from, the one source *that* made matter possible.
- Science must evolve to include qualia, as subjectivity isn’t a glitch in our scientific laws that we need to erase; it’s part of our foundation to understanding reality.
- Spirituality is no longer "unscientific" as, with qualia, it’s just a different level of science - just flipped inside-out.

Are we just individual specks of consciousness waking up to its true, complete self? Let me know your thoughts below!

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CONSCIOUSNESS

What a Contest of Consciousness Theories Really Proved

A five-year "adversarial collaboration" of consciousness theorists led to a stagy showdown in front of an audience. It crowned no winners — but it can still claim progress.

Introduction

Science routinely puts forward theories, then batters them with data till only one is left standing. In the fledgling science of consciousness, a dominant theory has yet to emerge. More than 20 are still taken seriously.

It's not for want of data. Ever since Francis Crick, the co-discoverer of DNA's double helix, legitimized consciousness as a topic for study more than three decades ago, researchers have used a variety of advanced technologies to probe the brains of test subjects, tracing the signatures of neural activity that could reflect consciousness. The resulting avalanche of data should have flattened at least the flimsier theories by now.

Five years ago, the Templeton World Charity Foundation initiated a series of "adversarial collaborations" to coax the overdue winnowing to begin. This past June saw the results from the first of these collaborations, which pitted two high-profile theories against each other: global neuronal workspace theory (GNWT) and integrated information theory (IIT). Neither emerged as the outright winner.

The results, announced like the outcome of a sporting event at the 26th meeting of the Association for the Scientific Study of Consciousness (ASSC) in New York City, were also used to settle a 25-year bet between Crick's longtime collaborator, the neuroscientist Christof Koch(opens a new tab) of the Allen Institute for Brain Science, and the philosopher David Chalmers() of New York University, who coined the term "the hard problem" to challenge the presumption that we can explain the subjective feeling of consciousness by analyzing the circuitry of the brain.

The neuroscientist Christof Koch of the Allen Institute for Brain Science deemed the mixed results of the first adversarial collaboration on consciousness to be "a victory for science."
Erik Dinnel

Onstage at NYU's Skirball Center, following interludes of rock music, a rap performance on consciousness and the presentation of the results, the neuroscientist conceded the bet to the philosopher: The neural correlates of consciousness had not yet been nailed down.

Nevertheless, Koch proclaimed, "It's a victory for science."

But was it? The event has received mixed reviews. Some researchers point to the failure to meaningfully test the differences between the two theories. Others highlight the success of the project in driving consciousness science forward, both by delivering large, novel, skillfully executed data sets and by inspiring other contestants to engage in their own adversarial collaborations.

The Correlates of Consciousness

When Crick and Koch published their landmark paper() "Towards a Neurobiological Theory of Consciousness" in 1990, their aim was to place consciousness — for 2,000 years the stomping ground of philosophers— onto a scientific footing. Consciousness in its entirety, they argued, was too broad and controversial a concept to serve as a starting point.

Instead, they focused on one scientifically tractable aspect of it: visual perception, which involves becoming conscious of seeing, for instance, the color red. The scientific goal was to find the circuitry that correlated with that experience, or, as they put it, the "neural correlates of consciousness."

Decoding the first stages of visual perception had already proved a fertile ground for science. Patterns of light falling on the retina send signals to the visual cortex in the back of the brain. There, upwards of 12 distinct neural modules process the signals corresponding to edges, color and movement in the images. Their output combines to build up a final dynamic picture of what we consciously see.

What clinched the usefulness of visual perception for Crick and Koch was that the final link in that chain — consciousness — could be detached from the rest. Since the 1970s, neuroscientists have known of people with "blindsight" who have no experience of vision because of damage to their brain, yet who can navigate a room without bumping into obstacles. While they retain the ability to process an image, they're missing the ability to be conscious of it.

In this famous illusion, the brain’s mechanism for producing consciousness allows us to experience the image as either a vase or two faces — but not both simultaneously.
Nevit Dilmen

All of us can experience a form of this disconnection. Consider the well-known optical illusion that can be perceived as either a vase or two faces in profile. At any moment we can see it only as one or the other. Something in how our brain processes perceptions prevents us from being conscious of both simultaneously.

Experimental psychologists can take advantage of that quirk through the phenomenon of binocular rivalry. Our brain normally has no trouble combining the slightly different, overlapping images it receives from the left and right eyes. But if the images are very different, instead of merging, they become rivals: First one image dominates our perception, then the other. When the neuroscientist Nikos Logothetis() of the Max Planck Institute for Biological Cybernetics described binocular rivalry in 1996, Crick was so excited, he proclaimed that neural correlates of consciousness would be found by the end of the 20th century. (Similar enthusiasm led to Koch’s bet with Chalmers.)

Over the last two decades, ever more sophisticated brain scanners have monitored test subjects as their perceptions were manipulated during studies of consciousness. Trickles of data have become cascades, yet rather than being washed away, theories of consciousness have multiplied.

A broad division among these many theories is that some of them, like GNWT, require the participation of the parts of the brain that enable cognition, where we “think,” while IIT and others claim that the neural correlates depend on brain areas involved in perception, where we “sense.” The ideas are often casually described as “front-of-the-brain” theories versus “back-of-the-brain” theories (though the actual anatomical distinction is less cut and dried than that). This intriguing bifurcation echoes old philosophical disagreements over whether consciousness is about thinking, as in Descartes’ “I think, therefore I am,” or about “not thinking,” as in the state experienced by a meditating yogi.

Merrill Sherman/*Quanta Magazine*

To the neuroscientist Stanislas Dehaene() of the Collège de France, the chief architect of GNWT, thinking is a core part of the conscious state. Referring to IIT, he told me, "It's a big difference between our theories. I don't believe in purified consciousness."

GNWT maintains that a tiny subset of the information we constantly process unconsciously is selected to pass through a bottleneck into a conscious "workspace." There, the information is integrated and broadcast to other brain areas to make it globally available for decision-making and learning. "The 'workspace' is there for a function," Dehaene said. Because decision-making and learning are responsibilities of the prefrontal cortex, the front of the brain is deemed crucial for consciousness.

The germ of the idea was originally proposed in 1988 by the psychologist Bernard Baars(), now at the Society for Mind Brain Sciences, who saw an analogy to the "blackboard" of early artificial intelligence system architectures where independent programs shared information. Dehaene then tied that conceptual template to the findings of cutting-edge neuroscience and used computational models to develop GNWT.

The neuroscientist Giulio Tononi of the University of Wisconsin, Madison, developed the integrated information theory by mathematically formulating five axioms about consciousness.
John Maniaci/UW Health

IIT makes no analogies to AI architecture. Giulio Tononi(), a neuroscientist and psychiatrist at the University of Wisconsin, Madison, developed the theory by starting with five axioms about consciousness: It is intrinsic to the entity who has it; its composition is structured; it is information-rich; it is integrated rather than reducible to components; and it is exclusive of other experiences. He then developed mathematical descriptions to fit those axioms. To Tononi and other IIT theorists, the neural structure most consistent with those mathematical descriptors is a gridlike architecture associated with sensory regions, which they've dubbed the "hot zone."

But GNWT and IIT are only two of the theories that locate key elements of consciousness at opposite poles of the brain. There are other cognitive, front-of-the-brain concepts including several higher-order theories (HOTs) and active inference theory, and a variety of sensory, back-of-the-brain concepts such as the closely related first-order theories and localist theories.

Eliminating some of them by testing their predictions against data from living brains might seem like simplicity itself. Unfortunately, that has not turned out to be true.

Finding What They Look For

For years, researchers devised clever experiments in which test subjects reported when they became conscious of an object while psychological tricks or illusions were used to distract them. Those results often showed that the moment of conscious perception correlated with activity in the prefrontal cortex, favoring something like a GNWT or other front-of-the-brain explanation. But philosophers and experimenters began complaining that those studies could be measuring the neural activity associated with the task of reporting rather than the consciousness itself.

"No-report" paradigms were therefore developed as a workaround. A popular one involved binocular rivalry. If a leftward-moving face is shown to a test subject's left eye and a rightward-moving house to their right eye, their conscious perception will flip between the two images. Researchers can identify the perceived image without a report by tracking which way the eyes are moving. Data at the time suggested that in these no-report paradigms, the signal for conscious perception localized to the back of the brain.

Yet theorists were rarely persuaded by any of the experiments and data. In a 2016 review, the IIT camp dismissed the report-based experiments as methodologically flawed. The debate continued in 2017 with dueling articles in the *Journal of Neuroscience.* In one of them, Hakwan Lau(), now at the Riken Center for Brain Science in Japan, and his colleagues offered the riposte that no-report paradigms were themselves rife with confounding variables.

A further complication was that the experimental results depended on the type of brain recording technique used. That's not surprising since each technology provides a different lens into the brain. Functional magnetic resonance imaging (fMRI), for instance, tracks blood flow and offers good spatial resolution but is too sluggish to keep up with the pace of chatter among the neurons. Magnetoencephalography (MEG), on the other hand, tracks brain chatter but has poorer spatial resolution. It also makes a difference whether researchers are measuring signal strength in specific locations of the brain or analyzing patterns over wider areas.

The upshot was that despite the wealth of experimental data gathered to study the correlates of consciousness, the uncertainties gave theorists room to claim that the data supported their preferred explanations.

The neuroscientist Liad Mudrik (left) of Tel Aviv University and her doctoral student Itay Yaron (right) have compiled evidence that the goal of using experimental studies to test theories of consciousness is often thwarted by biases that creep into the design of the experiments.
Sophie Kelly

Liad Mudrik(), a Tel Aviv University neuroscientist, believes that part of the problem lies in the way the studies were (and often continue to be) designed. A recent survey by her doctoral student Itay Yaron() looked at more than 400 published consciousness experiments and found that it was largely possible to predict which theory would be supported solely on the basis of the design of the experiment, without knowing anything about the results.

Adversarial Collaboration

Five years ago, Dawid Potgieter(), the head of the special programs section of the Templeton World Charity Foundation, was astonished to find that there were still so many viable theories about consciousness. He felt the time was ripe to do something about it.
Koch suggested a head-to-head contest, which had sometimes been used to settle controversies in physics. There were precedents in psychology too. In the 1980s, the psychology researcher Dan Kahneman() of Princeton University coined the term "adversarial collaboration" to describe exercises in which scientists with opposing views jointly developed experiments. By working together, they could smooth out disagreements over goals and methodology that might undermine the conclusions of the work. (Kahneman hit on this approach while resolving a theoretical feud he was having with his psychologist colleague and wife, Anne Treisman().)

Dawid Potgieter, acting on behalf of the Templeton World Charity Foundation, convened a workshop five years ago to develop adversarial collaborations for testing theories of consciousness.
Templeton World Charity Foundation

Potgieter was keen to try. In March 2018, he and Koch hosted a weekend workshop at the Allen Institute in Seattle for 14 participants. It included three theorists — Dehaene, Tononi and Lau, who champions HOTs — as well as Chalmers and two other philosophers, four psychologists, two neuroscientists, a neurologist and Potgieter as a representative of the Templeton Foundation. Their charge was to collaboratively design new experiments to iron out all the past wrinkles and discriminate cleanly between the theories.

Three of the psychologists — Mudrik, Lucia Melloni() of the Max Planck Institute and Michael Pitts() of Reed College in Portland — already had a history of challenging theories of consciousness. "At some point, I think Giulio suggested, 'Why don't the three of you lead the project?'" Pitts recalled. "We had no idea what we were in for. It's consumed our lives."

Over the next nine months, discussions continued. The theorists drilled down into their theories and offered new predictions — one of the novel contributions of the collaboration. Mudrik was impressed by the willingness of the adversaries to negotiate. "It takes a lot of courage; you're putting your neck on the line," she said.

The team came up with two experimental designs for disentangling the predictions of IIT and GNWT. They never came up with predictions that were different enough to disentangle GNWT and HOTs, so HOTs were left for a different adversarial collaboration involving Lau and the NYU philosopher Ned Block(), who champions first order theories.

Tononi was particularly keen on the design of the first GNWT-versus-IIT experiment. Since tasks had created such a wrinkle in past experiments, it would iron them out by varying the tasks to see how that affected conscious perception.

The test subjects would be presented with a series of varied images, such as faces, clocks and letters of the alphabet in different fonts. They would see each image for 0.5 to 1.5 seconds. At the beginning of each series, two specific images would be defined as targets (say, the face of a woman and a vintage clock), and participants were given the reporting task of pressing a button if they saw either of them. Other faces and objects in the images would therefore be task-relevant (because they fell into the same categories as the targets), but no report was required. Other types of images in the series, such as alphabet letters and meaningless symbols, would be task-irrelevant. The test was run repeatedly with different targets in the series so that each set of stimuli could be tested as both task-relevant and task-irrelevant. State-of-the-art brain signal decoders would correlate neural firing patterns with what the subjects were seeing.

GNWT predicted that the brain patterns corresponding to conscious perceptions of objects would be similar whether a task was involved or not. The brain decoders should be able to identify a distinctive signal associated with a target image regardless of the task. Moreover, it ought to be possible to detect the "ignition signal" of a new conscious percept entering the brain's workspace as well as an "off signal" clearing it.

IIT, on the other hand, predicted that the brain patterns of consciousness would vary with the tasks, because carrying out a task would involve the prefrontal cortex and perception stripped of a task would not. This "pure" form of consciousness would only require the sensory hot zone at the back of the brain. The connectivity and duration of the signals for consciousness of an image would match the duration of the visual stimulus.

The psychology researcher Daniel Kahneman of Princeton University believes strongly in the value of adversarial collaborations for advancing science, even though he finds that the results rarely change the minds of the adversaries.
Roger Parkes/Alamy Stock Photo

Dehaene favored the second experiment, which also involved the comprehensive decoding of brain patterns. Test subjects would be randomly exposed to faces and objects flashed on a screen while they played a distracting Tetris-like video game. Shortly after an image was shown, the game would stop and the subject would be asked whether they saw it. Dehaene preferred this design because it offered a more clear-cut contrast between conscious and unconscious mental states, which he considered essential to getting unambiguous data on the correlates of consciousness.

Because Kahneman was so familiar with adversarial collaborations, he mentored the three project leaders. But he also warned them that, in his experience, adversaries don't change their minds after seeing the results of their collaborations. Instead, when faced with an inconvenient result, "their IQ leaps 15 points" as they invent ways to accommodate the new, conflicting data, he said.

Mixed Results, With No Losers

The researchers set to work performing the experiments suggested by the workshop team. The GNWT-versus-IIT experiment that Tononi liked best, which tested with different levels of tasks, finished up first. It was carried out in two different labs using fMRI, MEG and intracranial electroencephalography. In all, six theory-neutral labs and 250 test subjects participated.

On the evening of June 23, an excited audience gathered at NYU to learn the outcome of that experiment. Writ large on a giant screen, the results were shown on a chart marked by red and green highlights, as though the researchers were reporting on a steeplechase with three types of hurdles.

The first hurdle checked how well each theory decoded the categories of the objects that the subjects saw in the presented images. Both theories performed well here, but IIT was better at identifying the orientation of objects.

The second hurdle tested the timing of the signals. IIT predicted sustained, synchronous firing in the hot zone for the duration of the conscious state. While the signal was sustained, it did not remain synchronous. GNWT predicted an "ignition" of the workspace followed by a second spike when the stimulus disappeared. Only the initial spike was detected. In the on-screen scoring for the NYU audience, IIT pulled ahead.

The third hurdle concerned overall connectivity across the brain. GNWT scored better than IIT here, largely because some analyses of the results supported GNWT predictions while the signals across the hot zone were not synchronous.

Both theories were challenged by the results. But in the final tally on screen at the event, IIT scored more green highlights than GNWT, and the audience responded as though a victor had been crowned. Melanie Boly() of the University of Wisconsin, Madison, a supporter of IIT, was buoyed enough by the outcome to declare onstage: "The results corroborate IIT's overall claim that posterior cortical areas are sufficient for consciousness, and neither the involvement of [the prefrontal cortex] nor global broadcasting are necessary."

The neuroscientist Stanislas Dehaene of the Collège de France, who developed the global neuronal workspace theory, considers thinking to be a core part of consciousness.
Abaca Press / Alamy Stock Photo

When Dehaene took to the stage, he did not admit defeat either. "I've decided to follow the advice of Dan Kahneman," he quipped. He professed to be happy because “the most interesting part of this experiment was the task-irrelevant stimuli.” The question was whether they would indicate the ignition of a conscious percept in the frontal brain. “The answer is yes!” he said.

Later, Dehaene suggested to me that the hurdles for IIT were set lower than those for his theory. “There was no real test of the complex mathematical core of [IIT],” he said. And as Block noted in his remarks that night, the finding that there was support for the back-of-the-brain theories does not specifically support IIT.

Notwithstanding the slightly higher number of green marks scored by IIT, the project leaders themselves are adamant that there was no winner. “These results confirm some predictions of IIT and GNWT, while substantially challenging both theories,” they wrote() in a paper describing the results posted on the biorxiv.org preprint server.

Just as Kahneman predicted, the adversaries explained away the discrepancies. Boly argued that the failure to detect sustained synchrony in the hot zone “may be due to sampling limitations.” Dehaene suspected that no “off” signal was detected because the subjects allowed their minds to wander. “My claim is that consciousness became decoupled from the stimulus,” he said.

Boly and Dehaene now await the results of the second experiment, involving the Tetris-like game distraction. Those results won’t be available until next year.

The Pace of Progress

So has science been advanced? Not everyone thinks so.

Some researchers, such as Olivia Carter(), a psychologist at the University of Melbourne and past president of the ASSC, think the two theories were too far apart for their predictions to be meaningfully compared. “My personal feeling is they are testing totally different things,” she said. “IIT is focusing on phenomenal content, and GNWT is much more interested in working memory and attention.”

That assessment seems apt. Yet it's also frustrating, given that a dispositive comparison was the stated purpose of the adversarial collaboration in the first place. If it's a victory for science, it seems like a qualified one.

The Monash University philosopher [Jakob Hohwy](), who is part of another Templeton-funded adversarial collaboration, sees it differently. "This goes to the philosophy of science," he said. He points out the field is still divided over such fundamentals as the definition of consciousness, whether it is closer to thinking or feeling, and even whether self-reported results truly confound the data. For Hohwy, this kind of collaborative effort is the way to move forward. "We will find out as we go along in exactly this type of adversarial collaboration," he said.

Others, like the computational neuroscientist [Megan Peters]() of the University of California, Irvine, bristled at media coverage that reported the results as a two-horse race between GNWT and IIT rather than a field with multiple contenders. Instead of focusing on winners and losers, Peters said, it's important to see that science advances by learning from each experimental hurdle. (Having attended the proceedings that night, however, I can attest that the event was arranged to resemble a sporting event.)

Still, Peters remains a fan of adversarial collaborations. During the Covid-19 lockdown, she was inspired by the Templeton process to help organize [a series of workshops]() hosted by the Cognitive Computational Neuroscience conference. In these "generative adversarial collaborations," researchers engaged in robust debate. "Watching the teams chew on stuff was instructive," she said.

The first adversarial collaboration on consciousness may not have succeeded in winnowing out any theories from the field. But it did force theorists to make more tangible predictions, and it made experimentalists work out new techniques. "The findings of the collaboration remain extremely valuable," wrote the University of Sussex neuroscientist [Anil Seth]() in [a commentary]() after the June event. "They will push forward the development of both IIT and [GNWT] — and other theories of consciousness, too — by providing new constraints and new explanatory targets."

For Melloni, the fact that the adversaries have not changed their minds does not detract from the value of the process. "As Kahneman says, people don't change their mind, yet the way they react to the challenges makes their theory progress or degenerate," she said. "If the latter, [then] over time the theory 'dies' and scientists abandon it."

Corrections added August 24, 2023:
A missing paragraph describing the adversarial collaborations arising from the workshop, including one for testing HOTs and first order theories, was restored. Also, some details of the descriptions of the experiments that the adversarial collaboration developed for testing GNWT against IIT were clarified.

NEUROSCIENCE

Neuroscience Readies for a Showdown Over Consciousness Ideas

To make headway on the mystery of consciousness, some researchers are trying a rigorous new way to test competing theories.

Neuroscientists are preparing to test their ideas about the origins of consciousness — the cognitive state of experiencing your own existence.

Introduction

All topics

Some problems in science are so hard, we don't really know what meaningful questions to ask about them — or whether they are even truly solvable by science. Consciousness is one of those: Some researchers think it is an illusion; others say it pervades everything. Some hope to see it reduced to the underlying biology of neurons firing; others say that it is an irreducibly holistic phenomenon.

The question of what kinds of physical systems are conscious "is one of the deepest, most fascinating problems(opens a new tab) in all of science," wrote the computer scientist Scott Aaronson(opens a new tab) of the University of Texas at Austin. "I don't know of any philosophical reason why [it] should be inherently unsolvable" — but "humans seem nowhere close to solving it."

Now a new project currently under review hopes to close in on some answers. It proposes to draw up a suite of experiments that will expose theories of consciousness to a merciless spotlight, in the hope of ruling out at least some of them.

If all is approved and goes according to plan, the experiments could start this autumn. The initial aim is for the advocates of two leading theories to agree on a protocol that would put predictions of their ideas to the test. Similar scrutiny of other theories will then follow.

If it were to take a hundred years to solve the mystery of consciousness, I hope we can cut it down to fifty.

Dawid Potgieter, Templeton World Charity Foundation

Whether or not this project, funded by the Templeton World Charity Foundation(opens a new tab), narrows the options for how consciousness arises, it hopes to establish a new way to do science for difficult, contentious problems. Instead of each camp championing its own view and demolishing others, researchers will collaborate and agree to publish in advance how discriminating experiments might be conducted — and then respect the outcomes.

Dawid Potgieter(opens a new tab), a senior program officer at the Templeton World Charity Foundation who is coordinating the endeavor, says that this is just the beginning of a sustained effort to winnow down theories of consciousness. He plans to set up several more of these "structured adversarial collaborations" over the next five years.

He is realistic about the prospects. "I don't think we are going to come to a single theory that tells us everything about consciousness," he said. "But if it were to take a hundred years to solve the mystery of consciousness, I hope we can cut it down to fifty."

A Workspace for Awareness

Philosophers have debated the nature of consciousness and whether it can inhere in things other than humans for thousands of years, but in the modern era, pressing practical and moral implications make the need for answers more urgent. As artificial intelligence (AI) grows increasingly sophisticated, it might become impossible to tell whether one is dealing with a machine or a human merely by interacting with it — the classic Turing test. But would that mean AI deserves moral consideration?

Understanding consciousness also impinges on animal rights and welfare, and on a wide range of medical and legal questions about mental impairments. A group of more than 50 leading neuroscientists, psychologists, cognitive scientists and others recently called for(opens a new tab) greater recognition of the importance of research on this difficult subject. "Theories of consciousness need to be tested rigorously and revised repeatedly amid the long process of accumulation of empirical evidence," the authors said, adding that "myths and speculative conjectures also need to be identified as such."

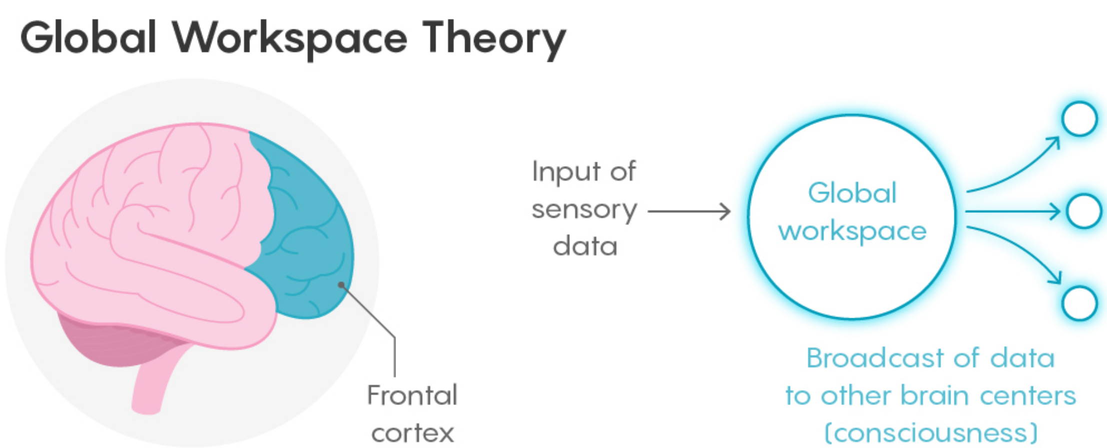
The cognitive scientist Stanislas Dehaene of the Collège de France in Paris is one of those behind the global workspace theory of consciousness, which asserts that conscious behavior arises when sensory information collected in a cognitive "workspace" is broadcast to other brain centers.
Per Henning/NTNU(opens a new tab)

You can hardly do experiments on consciousness without having first defined it. But that's already difficult because we use the word in several ways. Humans are conscious beings, but we can lose consciousness, for example under anesthesia. We can say we are conscious of something — a strange noise coming out of our laptop, say. But in general, the quality of consciousness refers to a capacity to experience one's existence rather than just recording it or responding to stimuli like an automaton. Philosophers of mind often refer to this as the principle that one can meaningfully speak about what it is to be "like" a conscious being — even if we can never actually have that experience beyond ourselves.

Plenty of cognition takes place outside the grasp of conscious awareness — in that sense, we respond to some cues and stimuli "unconsciously." A distinguishing feature of our minds, however, is that we can hold on to a piece of information, an idea or an intention as a motivation for subsequent decisions and behaviors. If we're hungry, we salivate as a reflex, but we might also choose to eat, go to the kitchen and get what we want from the cupboard.

Some researchers, such as the cognitive scientist Stanislas Dehaene(opens a new tab) of the Collège de France in Paris, suggest that this conscious behavior arises when we hold a piece of information in a "global workspace(opens a new tab)" within the brain, where it can be broadcast to brain modules associated with specific tasks. This workspace, he says, imposes a kind of information bottleneck: Only when the first conscious notion slips away can another take its place. According to Dehaene, brain-imaging studies suggest this "conscious bottleneck" is a distributed network of neurons in the brain's prefrontal cortex.

This picture of consciousness is called global workspace theory (GWT). In this view, consciousness is created by the workspace itself — and so it should be a feature of any information-processing system capable of broadcasting information to other processing centers. It makes consciousness a kind of computation for motivating and guiding actions. "Once you have information and the information is made broadly available, in that act consciousness occurs," said Christof Koch(opens a new tab), chief scientist and president of the Allen Institute for Brain Science in Seattle.



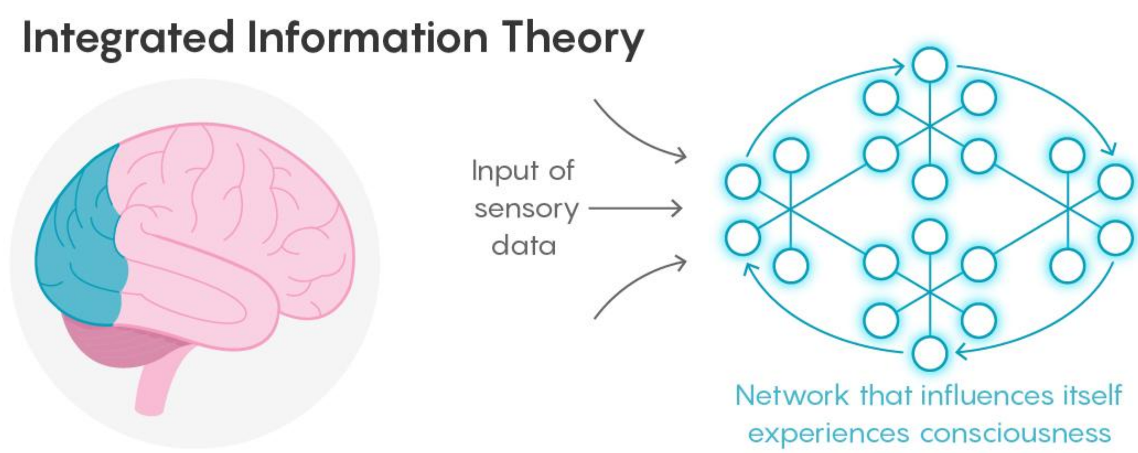
According to one theory, consciousness is a form of information processing. It occurs when sensory data for an experience go to a "global workspace" and are distributed to other centers. The architecture for this process in the brain may be in the frontal cortex .

Lucy Reading-Ikkanda/Quanta Magazine

But to Koch, the argument that all of cognition, including consciousness, is merely a form of computation "embodies the dominant myth of our age: that it's just an algorithm, and so is just a clever hack away." According to this view, he said, "very soon we'll have clever machines that model most of the features that the human brain has and thereby will be conscious."

He has been developing a competing theory in collaboration with its originator, the neuroscientist Giulio Tononi(opens a new tab) of the University of Wisconsin-Madison. They say that consciousness is not something that arises while turning inputs into outputs but rather an intrinsic property of the right kind of cognitive network, one that has specific features in its architecture. Tononi christened this view integrated information theory(opens a new tab) (IIT).

In contrast to GWT, which starts by asking what the brain does to create the conscious experience, IIT begins instead with the experience. "To be conscious is to have an experience," Tononi said. It doesn't have to be an experience about anything, although it can be; dreams, or some "blank mind" states attained by meditation also count as conscious experiences. Tononi has sought to identify the essential features of these experiences: namely, that they are subjective (they exist only for the conscious entity), structured (their contents relate to one another: "the blue book is on the table"), specific (the book is blue, not red), unified (there is only one experience at a time) and definitive (there are bounds to what the experience contains). From these axioms, Tononi and Koch claim to have deduced the properties that a physical system must possess if it is to have some degree of consciousness.



The integrated information theory argues that consciousness is intrinsic to cognitive networks that exert a "causal power" on themselves. The back of the brain might have the right architecture for this capacity.

Lucy Reading-Ikkanda/Quanta Magazine

IIT does not portray consciousness as information processing but rather as the causal power of a system to "make a difference" to itself. Consciousness, Koch said, is "a system's ability to be acted upon by its own state in the past and to influence its own future. The more a system has cause-and-effect power, the more conscious it is."

This harks back to the famous "cogito, ergo sum" dictum of René Descartes in the 17th century. "The one thing, the only thing, that is [a] given is my experience," Koch said. "That's Descartes' central insight."

To Tononi and Koch, systems in which information is merely "fed forward" to convert inputs to outputs, as in digital computers, can only be "zombies," which might act as if they are conscious but cannot truly possess that property. Much of Silicon Valley may believe that computers will eventually become conscious, but to Koch, unless those machines have the right hardware for consciousness, they will just constitute a "deep fake."

"Digital computers can simulate consciousness, but the simulation has no causal power and is not actually conscious," Koch said. It's like simulating gravity in a video game: You don't actually produce gravity that way.

'Surrounded and Immersed' in Consciousness

One of the most striking features of IIT is that it makes consciousness a matter of degree. Any system with the required network architecture may have some of it. "No matter whether the organism or artifact hails from the ancient kingdom of Animalia or from its recent silicon offspring, no matter whether the thing has legs to walk, wings to fly, or wheels to roll with," Koch wrote in his 2012 book *Consciousness: Confessions of a Romantic Reductionist*. "If it has both differentiated and integrated states of information, it feels like something to be such a system."

This view arouses a lot of skepticism. The influential American philosopher of mind John Searle(opens a new tab) of the University of California, Berkeley derides the idea as a form of panpsychism(opens a new tab): crudely, a belief that mind and awareness infuse the whole cosmos. In a withering critique of IIT(opens a new tab), Searle has asserted that "the problem with panpsychism is not that it is false; it does not get up to the level of being false. It is strictly speaking meaningless because no clear notion has been given to the claim." Consciousness, he wrote, "cannot be spread over the universe like a thin veneer of jam" — it "comes in units and panpsychism cannot specify the units."

To Christof Koch, the chief scientist and president of the Allen Institute for Brain Science, the argument that consciousness is merely a form of

computation "embodies the dominant myth of our age: that it's just an algorithm, and so is just a clever hack away." Unless artificial intelligences have the right features in their architecture, he says, they will never be more than "deep fakes."
Erik Dinnel

Koch, however, is perfectly happy to think that "we are surrounded and immersed" in consciousness. He believes "that consciousness is a fundamental, elementary property of living matter. It can't be derived from anything else."

But this doesn't mean it is spread equally everywhere. Koch and Tononi assert that, while consciousness can be an attribute of many things, a significant amount of it can exist only in particular kinds of things, notably human brains (indeed, in specific parts of human brains). And to turn IIT into a quantitative, testable theory, Koch and Tononi have formulated a criterion for what kinds of things those are.

To reflect how conscious an information-processing network is, Koch and Tononi define a measure of "information integration," which they call Φ (the Greek letter phi). It represents the amount of "irreducible cause-effect structure": how much the network as a whole can influence itself. This depends on interconnectivity of feedback. If a network can be divided into smaller networks that don't exert causal power on one another, then it will have a correspondingly low value of Φ no matter how many processing nodes it has.

[C]onsciousness is a fundamental, elementary property of living matter. It can't be derived from anything else.

Christof Koch, Allen Institute for Brain Science

Equally, "any system whose functional connectivity and architecture yield a Φ value greater than zero has at least a trifle of [conscious] experience," Koch said. That includes the biochemical regulatory networks found in every living cell, and also electronic circuits that have the right feedback architecture. Since atoms can influence other atoms, "even simple matter has a modicum of Φ." But systems that have enough Φ to "know" of their existence, as we do, are rare (although the theory anticipates that higher animals will also have a degree of that experience).

Because of this effort to make IIT quantitative and testable, Aaronson puts it(opens a new tab) "in something like the top 2 percent of all mathematical theories of consciousness ever proposed." He believes that the theory is flawed — but contrary to Searle, he says that "almost all competing theories of consciousness have been so vague, fluffy and malleable that they can only aspire to wrongness."

Seeking Neural Correlates

Koch would concur with that. "Everybody seems to have a pet theory of consciousness, but few of them are quantitative or predictive," he said. He believes that both GWT and IIT are testable. "Logically speaking, they could be wrong, or both could capture certain aspects of reality." How, though, do we test them?

Enter the Templeton World Charity Foundation, which has assigned $20 million to the task of testing theories of consciousness to destruction. It is starting with what Potgieter calls a "structured adversarial collaboration" involving IIT and GWT because they are able to make testable and contrasting predictions. The plan is for the proponents of the two theories to agree in advance to an experimental protocol that ought to distinguish whether either or both of the theories are wrong. "The condition was that the leaders of the theories would sign off on this protocol, in the sense of acknowledging that the predictions accurately represent the theory," Potgieter said. (He credited the willingness of Dehaene and Tononi "to put themselves on the line" as one of the considerations that led to the choice of GWT and IIT as the first theories on the block.)

Dawid Potgieter of the Templeton World Charity Foundation is coordinating the proposed experimental program for testing pairs of consciousness theories head to head.
Templeton World Charity Foundation

The collaboration will get a top journal to commit to publishing the outcome of the experiments, come what may. The study will also include replication experiments. "This is basically open science," Potgieter said. "If we can use the best practices in open science to demonstrate progress in an area where no one has done very much, it could show that it's a useful approach."

He says that the researchers now have a final experimental design to test incompatible predictions of GWT and IIT head-to-head. The details are yet to be disclosed, but they will deploy a battery of brain-monitoring techniques, such as functional magnetic resonance imaging (fMRI), electrocorticography and magnetoencephalography. The experiment seems to be "the first time ever that such an audacious, adversarial collaboration has been undertaken and formalized within the field of neuroscience," Potgieter added. He hopes that if the project is approved, the experimental work will be able to start after the summer and run for about three years, involving 10-12 labs.

What differences between the theories will the experiments test? One is in the location of consciousness in the brain. According to GWT, the "neural correlates of consciousness" — the patterns of neuron activity that reflect the conscious state — should show up in parts of the brain that include the parietal and frontal lobes of the cortex. The parietal lobe processes sensory data such as touch and spatial sense. The frontal lobe is associated with cognitive processing for "higher" functions such as memory, problem solving, decision-making and emotional expression.

But people who have had a large fraction of the frontal lobe removed — as used to happen in neurosurgical treatments of epilepsy — can seem remarkably normal, Koch says. According to IIT, the seat of consciousness is instead likely to be in the sensory representation in the back of the brain, where the neural wiring seems to have the right character. "I'm willing to bet that, by and large, the back is wired in the right way to have high Φ, and much of the front is not," Tononi said.

> [A]lmost all competing theories of consciousness have been so vague, fluffy and malleable that they can only aspire to wrongness.

Scott Aaronson, University of Texas at Austin

We can compare the locations of brain activity in people who are conscious or have been rendered unconscious by anesthesia, he says. If such tests were able to show that the back of the brain indeed had high Φ but was not associated with consciousness, he admits that "IIT would be very much in trouble."

A recent fMRI study(opens a new tab) of brain activity in volunteers who were either conscious or under general anesthesia, conducted by a group that included Dehaene, showed distinct patterns corresponding to the two states.

During periods of unconsciousness, brain activity persisted only among regions with direct anatomical connections, whereas during conscious activity, complex long-distance interactions did not seem constrained by the brain's "wiring."

However, one of the authors of the study, the physicist-turned-neuroscientist Enzo Tagliazucchi(opens a new tab) of the University of Buenos Aires and the Pitié-Salpêtrière Hospital in Paris, stresses that the findings don't yet clearly support any particular theory of consciousness. "It would be premature to frame our work within one theory or the other," he said. "It doesn't tip any balance, nor it is intended to do so."

Another prediction of GWT is that a characteristic electrical signal in the brain, arising about 300-400 milliseconds after a stimulus, should correspond to the "broadcasting" of the information that makes us consciously aware of it. Thereafter the signal quickly subsides. In IIT, the neural correlate of a conscious experience is instead predicted to persist continuously while the experience does. Tests of this distinction, Koch says, could involve volunteers looking at some stimulus like a scene on a screen for several seconds and seeing whether the neural correlate of the experience persists as long as it remains in the consciousness.

"To be conscious is to have an experience," according to the neuroscientist Giulio Tononi of the University of Wisconsin-Madison. For that reason, the integrated information theory model of consciousness that he originated begins by asking what features a system must have to produce an experience like that of consciousness.

John Maniaci/UW Health

Not everyone is optimistic that it will be possible to find rigorous, definitive ways of testing and adjudicating these two theories. "The current project is an attempt in good faith in this direction," said Francis Fallon(opens a new tab), a philosopher of mind at St. John's University in Queens, New York, who is involved in the Templeton project. But he noted that because both theories have already been shaped by existing empirical evidence, it would be surprising to find new data with which either seems fundamentally inconsistent.

Hakwan Lau(opens a new tab), a psychologist who studies behavioral neuroscience at the University of California at Los Angeles, is not convinced IIT is even a truly scientific theory. "IIT is based on armchair theorizing," he said. He thinks that what IIT advocates regard as the likely locus of consciousness doesn't necessarily follow from the theory but is just their subjective view. "To

make empirical predictions [of the theory] testable by current methods," he said, "many additional assumptions and approximations need to be made."
To him, Lau says, IIT and GWT are "so different that I don't know how to begin to compare them." In contrast, Tagliazucchi thinks it possible that the two are essentially the same theory(opens a new tab), but "developed from third- and first-person viewpoints."
The cognitive scientist Anil Seth(opens a new tab) of the University of Sussex in the U.K. shares reservations about whether the Templeton project might prove premature. A "definitive rebuttal or validation" seems unlikely, he said, because the theories "make too many different assumptions, have different relations to testability and may even be trying to explain different things. GWT seems mostly about function and cognitive access, while IIT is a theory based primarily on phenomenology, not function, and is difficult to test."
Tononi and his collaborators would counter that they have been developing experimental tests(opens a new tab) of IIT for many years — work that has led to the development of a crude but effective tool for evaluating consciousness in brain-damaged patients(opens a new tab). Yet even Tononi agrees that, because both theories are still under construction and remain so "far apart," it might be too much to expect a definite outcome. "Their predictions aren't as precise as in physics," he said.

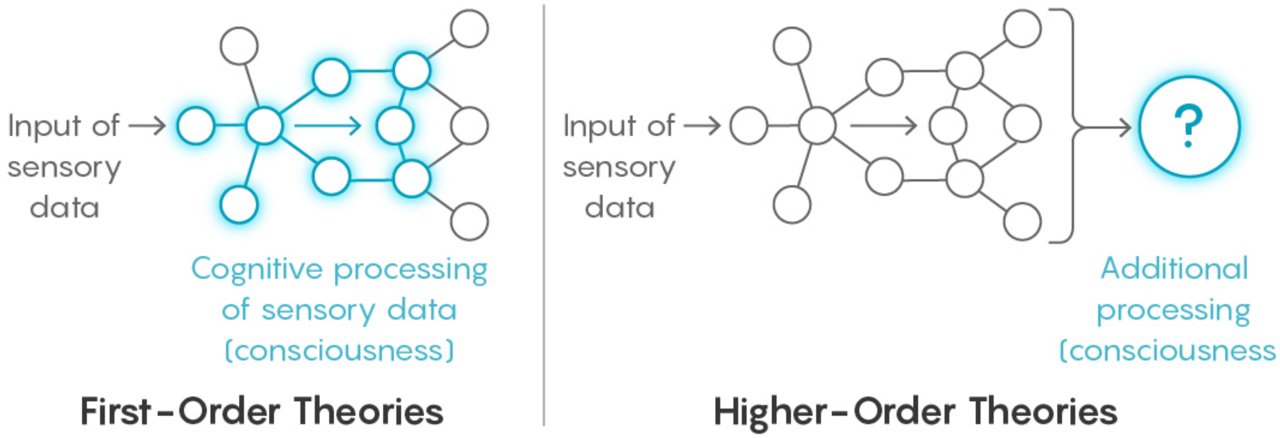
Still, he argues that "in the interests of making progress, you have to start with what you've got." Besides, the exercise "forces the theories to say something specific." Regardless of the outcome, Tononi feels sure that the tests will teach us something new and useful about the brain.

Other Contending Theories

No one imagines that eliminating GWT or IIT would solve the mystery of what consciousness is. For one thing, there are other serious theories, too.

Among them, two common classes are called first-order and higher-order theories (HOTs). "A first-order theory says that there's nothing more to the mind than the basic cognitive processing of sensory information," according to Lau. What brings some of that sensory information into consciousness, first-order theorists say, is something unidentified but intrinsic to how it's represented in the brain — for example, the dynamics of the interactions among elements in its neural network.

Two Other Classes of Consciousness Theories



First-order theories maintain that consciousness is simply a product of the cognitive processing of sensory information. Higher-order theories posit that consciousness involves something done to build on that cognitive representation of the sensory experience.

In contrast, he said, "higher-order theorists say that the mind does something with the representation, over and above the cognition itself, to produce consciousness." In a HOT, a conscious experience is not merely a record of the perceptions involved but involves some additional mechanism that draws on that representation. That higher-order state doesn't necessarily serve some function in processing the information, as in GWT; it just is.

"Compared to other existing theories, HOT can more readily account for complex everyday experiences, such as emotions and episodic memories," Lau and his colleagues, the philosopher Richard Brown(opens a new tab) of LaGuardia Community College and the neuroscientist Joseph LeDoux(opens a new tab) of New York University, wrote recently(opens a new tab).

The Templeton World Charity Foundation has assigned further funds to test such ideas as it will GWT and IIT. "I hope to host about nine meetings over the next five years, to bring together two or more incompatible theories and try to hash it out between those theories," Potgieter said. He admits that "it might be that none of the current ideas is correct."

It may also turn out that no scientific experiment can be the sole and final arbiter of a question like this one. “Even if only neuroscientists adjudicated the question, the debate would be philosophical,” Fallon said. “When interpretation gets this tricky, it makes sense to open the conversation to philosophers. Many of the neuroscientists in this field are already engaging in philosophy, some quite excellently.”

Potgieter hopes that the adversarial approach will allow progress on other big questions — like understanding how consciousness arose in the first place, or how life itself did. “Wherever there is a big question with a bunch of different theories that are all strong but all siloed away from each other, we will try to make progress by breaking down the silos,” he said.

“I think it is a wonderful initiative, and should be much more frequent in science,” Tononi said. “It forces the proponents to focus and enter some common framework. I think we all stand to gain one way or another.”

Anil Seth Finds Consciousness in Life’s Push Against Entropy

How does consciousness arise in mere flesh and blood? To the neuroscientist Anil Seth, our organic bodies are the key to the experience.

In his laboratory at the University of Sussex, the neuroscientist Anil Seth monitors brain activity for clues to the origins of consciousness.

Tom Medwell(opens a new tab) for Quanta Magazine

Introduction

biologybrainscognitive scienceconsciousnessneuroscienceQ&AAll topics

Anil Seth(opens a new tab) wants to understand how minds work. As a neuroscientist at the University of Sussex in England, Seth has seen firsthand how neurons do what they do — but he knows that the puzzle of consciousness spills over from neuroscience into other branches of science, and even into philosophy.

As he puts it near the start of his new book, *Being You: A New Science of Consciousness*(opens a new tab) (available October 19): “Somehow, within each of our brains, the combined activity of billions of neurons, each one a tiny biological machine, is giving rise to a conscious experience. And not just any conscious experience, your conscious experience, right here, right now. How does this happen? Why do we experience life in the first person?”

This puzzle — the mystery of how inanimate matter arranges itself into living beings with self-aware minds and a rich inner life — is what the philosopher David Chalmers(opens a new tab) called the “hard problem” of consciousness. But the way Seth sees it, Chalmers was overly pessimistic. Yes, it’s a challenge — but we’ve been chipping away at it steadily over the years.

“I always get a little annoyed when I read people saying things like, ‘Chalmers proposed the hard problem 25 years ago’ … and then saying, 25 years later, that ‘we’ve learned nothing about this; we’re still completely in the dark, we’ve made no progress,’” said Seth. “All this is nonsense. We’ve made a huge amount of progress.”

Quanta recently caught up with Seth at his home in Brighton via videoconference. The interview has been condensed and edited for clarity.

Why has this problem of consciousness been so vexing, over the centuries — harder, it seems, than figuring out what’s inside an atom or even how the universe began?

When we think about consciousness or experience, it just doesn’t seem to us to be the sort of thing that admits an explanation in terms of physics and chemistry and biology. There’s a suspicion that scientific explanation — by which I mean broadly materialist, reductive explanations, which have been so successful in other branches of physics and chemistry — just might not be up to the job, because consciousness is intrinsically private.

In this study of "displaced perception" in Seth's lab, a volunteer wears a virtual reality headset that provides a view of a mannequin's chest. This setup can trick the brain into "feeling" touches that aren't on the body.

That leap from the physical to the mental is something that philosophers have grappled with for centuries. René Descartes, for example, famously argued that nonhuman animals were akin to machines, while humans had something extra that made consciousness possible. In your book, you mention the work of a less familiar figure, the 18th-century French scholar Julien Offray de La Mettrie(opens a new tab). How did his views differ from those of Descartes, and how do they bear on your own work?

La Mettrie is a fascinating character, a polymath type of figure. I think of him as basically taking Descartes' ideas and extending them to their natural conclusions, by not being worried about what the [Catholic] Church might say. Descartes was always trying to finesse his arguments in order to avoid being burned alive, or otherwise being subject to harsh clerical treatment. Descartes considered nonhuman animals as "beast-machines." (This is a term I re-appropriate and hope to rehabilitate in my book.) The beast-machine for Descartes was the idea that nonhuman animals were machines made of flesh and blood, lacking the rational, conscious minds that bring humans closer to God.

La Mettrie said, "OK, if animals are flesh-and-blood machines, then humans are animals, too, of a certain sort." So just as there is a beast-machine, or a *bête machine*, you also have *l'homme machine* — "man machine(opens a new tab)." He just extended the same basic idea without this artificial division.

How does consciousness play into that picture? How is consciousness related to our nature as living machines, in a way that's continuous between humans and other animals? In my work — and in the book — I eventually get to the point that consciousness is not there in spite of our nature as flesh-and-blood machines, as Descartes might have said; rather, it's because of this nature. It is because we are flesh-and-blood living machines that our experiences of the world and of "self" arise.

You're clearly more drawn to some of the approaches to consciousness that researchers have put forward than others. For example, you seem to support the work that Giulio Tononi(opens a new tab) and his colleagues at the University of Wisconsin have been doing on "integrated information theory" (IIT). What is integrated information theory, and why do you find it promising?

Well, I find some bits of IIT promising, but not others. The promising bit comes from what Gerald Edelman(opens a new tab) and Tononi together observed, in the late '90s, which is that conscious experiences are highly "informative" and always "integrated."

It is because we are flesh-and-blood living machines that our experiences of the world and of "self" arise.

They meant information in a technical, formal sense — not the informal sense in which reading a newspaper is informative. Rather, conscious experiences are informative because every conscious experience is different from every other experience you ever have had, ever could have, or ever will have. Each one rules out the occurrence of a very, very large repertoire of alternative possible conscious experiences. When I look out of the window right now, I have never experienced this precise visual scene. It's an experience even more distinctive when combined with all my thoughts, background emotions and so on. And this is what information, in information theory, measures: It's the reduction of uncertainty among a repertoire of alternative possibilities.

As well as being informative, every conscious experience is also integrated. It's experienced "all of a piece": Every conscious scene appears as a unified whole. We don't experience the colors of objects separately from their shapes, nor do we experience objects independently of whatever else is going on. The many different elements of my conscious experience right now all seem tied together in a fundamental and inescapable way.

So at the level of experience, at the level of phenomenology, consciousness has these two properties that coexist. Well, if that's the case, then what Tononi and Edelman argued was that the mechanisms that underlie conscious experiences in the brain or in the body should also co-express these properties of information and integration.

By clicking to watch this video, you agree to our privacy policy.

Video: The neuroscientist Anil Seth of the University of Sussex discusses the principles, philosophy and experimentation that have brought scientists closer to understanding the phenomenon of consciousness.

Emily Buder/Quanta Magazine; Harry Genge(opens a new tab) for Quanta Magazine

Then is integrated information theory an attempt to quantify consciousness — to attach numbers to it?

Basically, yes. IIT proposes a quantity called phi which measures both information and integration and which according to the theory is identical to the amount of consciousness associated with a system.

One thing that immediately follows from this is that you have a nice post hoc explanation for certain things we know about consciousness. For instance, that the cerebellum(opens a new tab) — the "little brain" in the back of our head — doesn't seem to have much to do with consciousness. That's just a matter of empirical fact; the cerebellum doesn't seem much involved. Yet it has three-quarters of all the neurons in the brain. Why isn't the cerebellum involved? You can make up many reasons. But the IIT reason is a very convincing one: The cerebellum's wiring is not the right sort of wiring to generate co-expressed information and integration, whereas the cortex is, and the cortex is intimately related to consciousness.

I should also say the parts of IIT that I find less promising are where it claims that integrated information actually is consciousness — that there's an identity between the two. Among other things, taking this stance makes it almost impossible to measure for any nontrivial system. It also implies that consciousness is sort of everywhere, since many systems, not just brains, can generate integrated information.

You also seem fascinated by Karl Friston's "free-energy principle(opens a new tab)." Can you give a layperson-friendly explanation of what this is, and how it can help us understand minds?

I think the simplest articulation of the free-energy principle is this: Let's think about living systems — a cell or an organism. A living system maintains itself as separate from its environment. For example, I don't just dissolve into mush on the floor. It's an active process: I take energy in, and I maintain myself as a system which maintains its boundaries with the world.

This means that of all the possible states my body could be in — all the possible combinatorial arrangements of my different components — there's only a very, very small subset of "statistically expected" states that I remain in. My body temperature, for instance, remains in a very small range of temperatures, which is one of the reasons I stay alive. How do I do this? How does the organism do this? Well, it must minimize the uncertainty of the states that it's in. I have to actively resist the second law of thermodynamics(opens a new tab), so I don't dissipate into all kinds of states.

I think you can tell a rich story about the nature of consciousness and perception while retaining a broadly realist view of the world.

The free-energy principle is not itself a theory about consciousness, but I think it's very relevant because it provides a way of understanding how and why brains work the way they do, and it links back to the idea that consciousness and life are very tightly related. Very briefly, the idea is that to regulate things like body temperature — and, more generally, to keep the body alive — the brain uses predictive models, because to control something it's very useful to be able to predict how it will behave. The argument I develop in my book is that all our conscious experiences arise from these predictive models which have their origin in this fundamental biological imperative to keep living.

In your book, you discuss how things become less mysterious as we understand the science behind them better, and you wonder whether the mystery of consciousness might go away more in the manner of the mystery of "heat" or more like the mystery of "life." Can you expand on that a little bit?

There may be another connection between consciousness and life, but in this case the connection is more historical than literal. Historically, there is a commonality between the apparent mysteries of "life" and of "heat," which is that both eventually went away — but they went away in different ways.

Let's take heat first. Some years ago I read this brilliant book called *Inventing Temperature*(opens a new tab) by the philosopher and historian of science Hasok Chang(opens a new tab). Until then, I had not realized how complicated and rich and convoluted the story of heat and temperature was. Back in the 17th century, efforts to understand the basis of heat depended on ways to measure hotness and coolness — to come up with a scale of temperature and things like thermometers. But how do you build a thermometer until you have a reliable benchmark, a fixed point of temperature? And how do you get a temperature scale until you've got a reliable thermometer? It's a chicken-and-egg problem that was really problematic at the time. But it was managed: People, bit by bit, bootstrapped reliable thermometers into existence.

Once the ability to measure was in place, the story of heat turned out to be a maximally reductive scientific explanation. Previously, people had wondered whether heat was this thing that flowed between objects. Well, it's not. Heat turns out to be identical to something else — in this case, the mean molecular kinetic energy of atoms or molecules in a substance. That is what heat is.

Life is very different. Nobody measures how "alive" something is; it didn't get resolved in that way. But people still wondered what the essence of life really was — whether life required some *élan vital*, this "spark of life." Well, it does not. The key to unlocking life was to recognize that it is not just one thing. Life is a constellation concept — a cluster of related properties that come together in different ways in different organisms. There's homeostasis, there's reproduction, there's metabolism, and so on. With life there are also gray areas, things that from some perspectives we would describe as being alive, and from others not — like viruses and oil droplets, and now synthetic organisms. But by accounting for its diverse properties, the suspicion that we still needed an *élan vital*, a spark of life — some sort of vitalistic resonance — to explain it went away. The problem of life wasn't solved; it was "dissolved."

"The free-energy principle is not itself a theory about consciousness," Seth said, "but I think it's very relevant because it provides a way of understanding how and why brains work the way they do."

Harry Genge(opens a new tab) for Quanta Magazine

Which of these two ways do you suppose the puzzle of consciousness will play out?

Let's be optimistic and say that this problem, consciousness, will go away too. We'll look back in 50 years or 500 years, and we'll say, "Oh, yeah, we understand now." Will it be a story much like temperature and heat, where we say that consciousness is identical to something else — let's say, something like integrated information? IIT is in fact the theory that goes most strongly with the temperature analogy. Maybe it will turn out that way, if Giulio [Tononi] is right.

And what if consciousness ends up being more like life?

This, for me, is the more likely outcome. Here, it's going to be a case of saying consciousness is not this one big, scary mystery, for which we need to find a humdinger eureka moment of a solution. Rather, being conscious, much like being alive, has many different properties that will express in different ways among different people, among different species, among different systems. And by accounting for each of these properties in terms of things happening in brains and bodies, the mystery of consciousness may dissolve too.

You describe perception in your book as a "controlled hallucination." This gets us into somewhat philosophical territory. How do we decide what's "real" and what's an illusion?

I don't want to be misinterpreted, as I sometimes have — especially from the title of my TED Talk, "Your Brain Hallucinates Your Conscious Reality(opens a new tab)" — which has led to some people saying, "Go and stand in front of a bus and you'll revise that opinion." I don't need to revise it; that's already my opinion: Buses will hurt you. At the level of macroscopic, classical physics that we and buses inhabit, buses are real, whether you're looking at them or not.

I don't think we should be even trying to build a conscious machine. It's massively problematic ethically.

But the way we experience "bus-ness" — that which we experience as being [the qualities of] a bus — is different from its objective physical existence. Let's say the bus is red; now, redness is a mind-dependent property. Maybe bus-ness itself is also a mind-dependent property.

I don't go all the way to what in philosophy you might call some version of idealism(opens a new tab) — that everything is a property of the mental. Some people do. This is where I diverge a little bit from people like [the cognitive scientist] Donald Hoffman(opens a new tab). We line up in agreeing that perception is an active construction in the brain and that the goal of perception is not to create a veridical, accurate representation of the real world, but is instead geared toward helping the survival prospects of an organism. We see the world not as it is, but as it's useful for us to do so. But he goes further, ending up in a kind of panpsychist(opens a new tab) idealism that some degree of consciousness inheres in everything. I just don't buy it, frankly, and I don't think you need to go there. He might be right, but it's not testable. I think you can tell a rich story about the nature of consciousness and perception while retaining a broadly realist view of the world.

Where do you stand on the question of conscious machines?

I don't think we should be even trying to build a conscious machine. It's massively problematic ethically because of the potential to introduce huge forms of artificial suffering into the world. Worse, we might not even recognize it as suffering, because there's no reason to think that an artificial system having an aversive conscious experience will manifest that fact in a way we can recognize as being aversive. We will suddenly have ethical obligations to systems when we're not even sure what their moral or ethical status is. We shouldn't do this without having really laid down some ethical warning lines in advance.

One of the important qualities of consciousness that needs to be accounted for is that it is integrated. “The many different elements of my conscious experience right now all seem tied together in a fundamental and inescapable way,” Seth said.
Tom Medwell(opens a new tab) for Quanta Magazine

So we shouldn’t build conscious machines — but could we? Does it matter that a conscious machine wouldn’t be biological — that it would have a different “substrate,” as philosophers like to put it?

There’s still, for me, no totally convincing reason to believe that consciousness is either substrate-independent or substrate-dependent — though I do tend toward the latter. There are some things which are obviously substrate-independent. A computer that plays chess is actually playing chess. But a computer simulation of a weather system does not generate actual weather. Weather is substrate-dependent.

Where does consciousness fall? Well, if you believe that consciousness is some form of information processing, then you're going to say, "Well, you can do it in a computer." But that's a position you choose to take — there's no knock-down evidence for it. I could equally choose the position that says, no, it's substrate-dependent.

I'm still wondering what would make it substrate-dependent. Living things are made from cells. Is there something special about cells? How are they different from the components of a computer?

This is why I tend toward the substrate-dependent view. This imperative for self-organization and self-preservation in living systems goes all the way down: Every cell within a body maintains its own existence just as the body as a whole does. What's more, unlike in a computer where you have this sharp distinction between hardware and software — between substrate and what "runs on" that substrate — in life, there isn't such a sharp divide. Where does the mind-ware stop and the wetware start? There isn't a clear answer. These, for me, are positive reasons to think that the substrate matters; a system that instantiates conscious experiences might have to be a system that cares about its persistence all the way down into its mechanisms, without some arbitrary cutoff. No, I can't demonstrate that for certain. But it's one interesting way in which living systems are different from computers, and it's a way which helps me understand consciousness as it's expressed in living systems.

But conscious or not, you're worried that our machines will one day seem conscious?

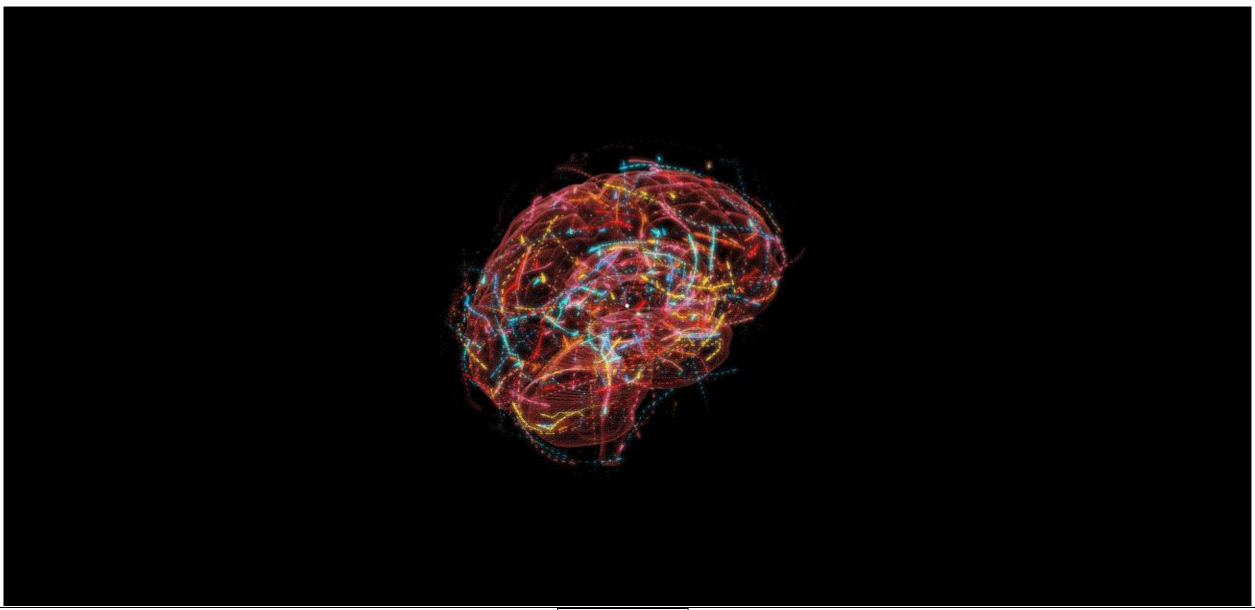
I think the situation we're much more likely to find ourselves in is living in a world where artificial systems can give the extremely compelling impression that they are conscious, even when they are not. Or where we just have no way of knowing, but the systems will strongly try to convince us that they are.

I just read a wonderful novel, *Klara and the Sun*(opens a new tab), by Kazuo Ishiguro, which is a beautiful articulation of all the ways in which having systems that give the appearance of being conscious can screw with our human psyches and minds. Alex Garland's film *Ex Machina*(opens a new tab) does this beautifully. *Westworld*(opens a new tab) does it too. *Blade Runner*(opens a new tab) does it. Literature and science fiction have addressed this question, I think, much more deeply than much of AI research has — at least so far.

NEUROSCIENCE

A New Spin on the Quantum Brain

A new theory explains how fragile quantum states may be able to exist for hours or even days in our warm, wet brain. Experiments should soon test the idea.



davidope(opens a new tab) for Quanta Magazine

Introduction

The mere mention of "quantum consciousness" makes most physicists cringe, as the phrase seems to evoke the vague, insipid musings of a New Age guru. But if a new hypothesis proves to be correct, quantum effects might indeed play some role in human cognition. Matthew Fisher(opens a new tab), a physicist at the University of California, Santa Barbara, raised eyebrows late last year when he published a paper(opens a new tab) in *Annals of Physics* proposing that the nuclear spins of phosphorus atoms could serve as rudimentary "qubits" in the brain — which would essentially enable the brain to function like a quantum computer.

As recently as 10 years ago, Fisher's hypothesis would have been dismissed by many as nonsense. Physicists have been burned by this sort of thing before, most notably in 1989, when Roger Penrose proposed that mysterious protein structures called “microtubules” played a role in human consciousness by exploiting quantum effects. Few researchers believe such a hypothesis plausible. Patricia Churchland, a neurophilosopher at the University of California, San Diego, memorably opined(opens a new tab) that one might as well invoke “pixie dust in the synapses” to explain human cognition.

Fisher’s hypothesis faces the same daunting obstacle that has plagued microtubules: a phenomenon called quantum decoherence. To build an operating quantum computer, you need to connect qubits — quantum bits of information — in a process called entanglement. But entangled qubits exist in a fragile state. They must be carefully shielded from any noise in the surrounding environment. Just one photon bumping into your qubit would be enough to make the entire system “decohere,” destroying the entanglement and wiping out the quantum properties of the system. It’s challenging enough to do quantum processing in a carefully controlled laboratory environment, never mind the warm, wet, complicated mess that is human biology, where maintaining coherence for sufficiently long periods of time is well nigh impossible.

Over the past decade, however, growing evidence suggests that certain biological systems might employ quantum mechanics. In photosynthesis, for example, quantum effects(opens a new tab) help plants turn sunlight into fuel. Scientists have also proposed(opens a new tab) that migratory birds have a “quantum compass” enabling them to exploit Earth’s magnetic fields for navigation, or that the human sense of smell could be rooted in quantum mechanics.
Fisher’s notion of quantum processing in the brain broadly fits into this emerging field of quantum biology. Call it quantum neuroscience. He has developed a complicated hypothesis, incorporating nuclear and quantum physics, organic chemistry, neuroscience and biology. While his ideas have met with plenty of justifiable skepticism, some researchers are starting to pay attention. “Those who read his paper (as I hope many will) are bound to conclude: This old guy’s not so crazy,” wrote(opens a new tab) John Preskill(opens a new tab), a physicist at the California Institute of Technology, after Fisher gave a talk there. “He may be on to something. At least he’s raising some very interesting questions.”
Senthil Todadri(opens a new tab), a physicist at the Massachusetts Institute of Technology and Fisher’s longtime friend and colleague, is skeptical, but he thinks that Fisher has rephrased the central question — is quantum processing happening in the brain? — in such a way that it lays out a road map to test the hypothesis rigorously. “The general assumption has been that of course there

is no quantum information processing that's possible in the brain," Todadri said. "He makes the case that there's precisely one loophole. So the next step is to see if that loophole can be closed." Indeed, Fisher has begun to bring together a team to do laboratory tests to answer this question once and for all.

Matthew Fisher has proposed a way for quantum effects to influence the workings of the brain.
Courtesy of Matthew Fisher

Finding the Spin

Fisher belongs to something of a physics dynasty: His father, Michael E. Fisher(opens a new tab), is a prominent physicist at the University of Maryland, College Park, whose work in statistical physics has garnered numerous honors and awards over the course of his career. His brother, Daniel Fisher(opens a new tab), is an applied physicist at Stanford University who specializes in evolutionary dynamics. Matthew Fisher has followed in their footsteps, carving out a highly successful physics career. He shared the prestigious Oliver E. Buckley Prize(opens a new tab) in 2015 for his research on quantum phase transitions.

So what drove him to move away from mainstream physics and toward the controversial and notoriously messy interface of biology, chemistry, neuroscience and quantum physics? His own struggles with clinical depression.

Fisher vividly remembers that February 1986 day when he woke up feeling numb and jet-lagged, as if he hadn't slept in a week. "I felt like I had been drugged," he said. Extra sleep didn't help. Adjusting his diet and exercise regime proved futile, and blood tests showed nothing amiss. But his condition persisted for two full years. "It felt like a migraine headache over my entire body every waking minute," he said. It got so bad he contemplated suicide, although the birth of his first daughter gave him a reason to keep fighting through the fog of depression.

Eventually he found a psychiatrist who prescribed a tricyclic antidepressant, and within three weeks his mental state started to lift. "The metaphorical fog that had so enshrouded me that I couldn't even see the sun — that cloud was a little less dense, and I saw there was a light behind it," Fisher said. Within nine months he felt reborn, despite some significant side effects from the medication, including soaring blood pressure. He later switched to Prozac and has continuously monitored and tweaked his specific drug regimen ever since.

His experience convinced him that the drugs worked. But Fisher was surprised to discover that neuroscientists understand little about the precise mechanisms behind how they work. That aroused his curiosity, and given his expertise in quantum mechanics, he found himself pondering the possibility of quantum processing in the brain. Five years ago he threw himself into learning more about the subject, drawing on his own experience with antidepressants as a starting point.

Since nearly all psychiatric medications are complicated molecules, he focused on one of the most simple, lithium, which is just one atom — a spherical cow, so to speak, that would be an easier model to study than Prozac, for instance. The analogy is particularly appropriate because a lithium atom is a sphere of electrons surrounding the nucleus, Fisher said. He zeroed in on the fact that the lithium available by prescription from your local pharmacy is mostly a common isotope called lithium-7. Would a different isotope, like the much more rare lithium-6, produce the same results? In theory it should, since the two isotopes are chemically identical. They differ only in the number of neutrons in the nucleus.

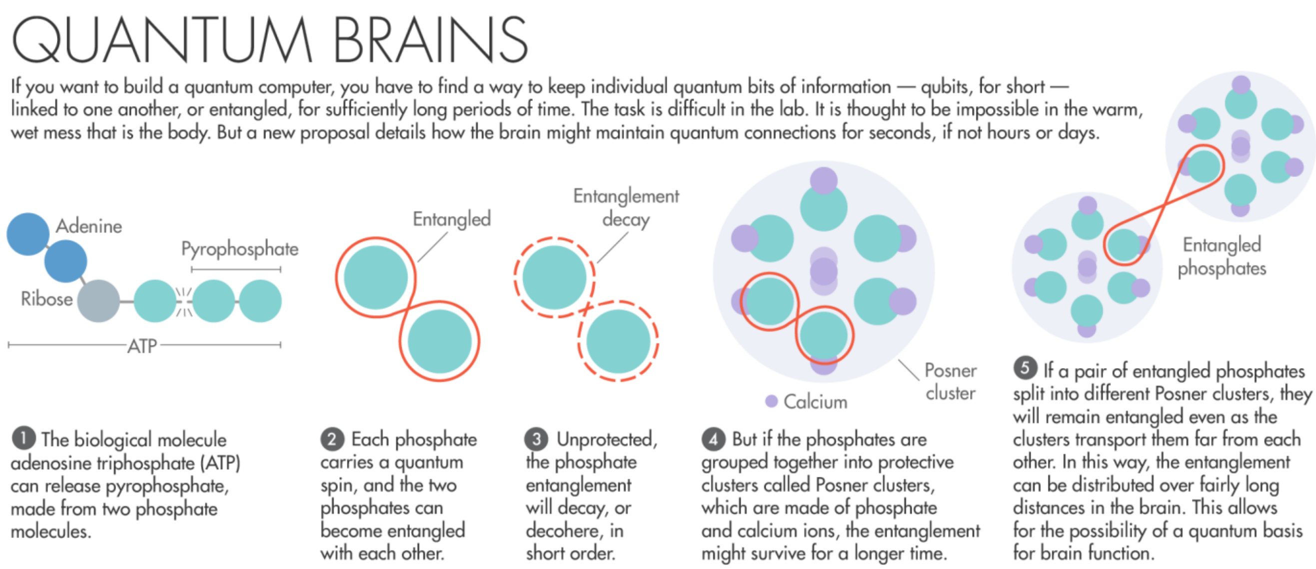
When Fisher searched the literature, he found that an experiment comparing the effects of lithium-6 and lithium-7 had been done. In 1986, scientists at Cornell University examined the effects of the two isotopes(opens a new tab) on the behavior of rats. Pregnant rats were separated into three groups: One group was given lithium-7, one group was given the isotope lithium-6, and the third served as the control group. Once the pups were born, the mother rats that received lithium-6 showed much stronger maternal behaviors, such as grooming, nursing and nest-building, than the rats in either the lithium-7 or control groups.

This floored Fisher. Not only should the chemistry of the two isotopes be the same, the slight difference in atomic mass largely washes out in the watery environment of the body. So what could account for the differences in behavior those researchers observed?

Fisher believes the secret might lie in the nuclear spin, which is a quantum property that affects how long each atom can remain coherent — that is, isolated from its environment. The lower the spin, the less the nucleus interacts with electric and magnetic fields, and the less quickly it decoheres.

Because lithium-7 and lithium-6 have different numbers of neutrons, they also have different spins. As a result, lithium-7 decoheres too quickly for the purposes of quantum cognition, while lithium-6 can remain entangled longer.

Fisher had found two substances, alike in all important respects save for quantum spin, and found that they could have very different effects on behavior. For Fisher, this was a tantalizing hint that quantum processes might indeed play a functional role in cognitive processing.



Quantum Protection Scheme

That said, going from an intriguing hypothesis to actually demonstrating that quantum processing plays a role in the brain is a daunting challenge. The brain would need some mechanism for storing quantum information in qubits for sufficiently long times. There must be a mechanism for entangling multiple qubits, and that entanglement must then have some chemically feasible means of influencing how neurons fire in some way. There must also be some means of transporting quantum information stored in the qubits throughout the brain.

This is a tall order. Over the course of his five-year quest, Fisher has identified just one credible candidate for storing quantum information in the brain: phosphorus atoms, which are the only common biological element other than hydrogen with a spin of one-half, a low number that makes possible longer coherence times. Phosphorus can't make a stable qubit on its own, but its coherence time can be extended further, according to Fisher, if you bind phosphorus with calcium ions to form clusters.

In 1975, Aaron Posner, a Cornell University scientist, noticed(opens a new tab) an odd clustering of calcium and phosphorous atoms in his X-rays of bone. He made drawings of the structure of those clusters: nine calcium atoms and six phosphorous atoms, later called "Posner molecules" in his honor. The clusters popped up again in the 2000s, when scientists simulating bone growth in artificial fluid noticed(opens a new tab) them floating in the fluid. Subsequent experiments found evidence(opens a new tab) of the clusters in the body. Fisher thinks that Posner molecules could serve as a natural qubit in the brain as well.

That's the big picture scenario, but the devil is in the details that Fisher has spent the past few years hammering out. The process starts in the cell with a chemical compound called pyrophosphate. It is made of two phosphates bonded together — each composed of a phosphorus atom surrounded by multiple oxygen atoms with zero spin. The interaction between the spins of the phosphates causes them to become entangled. They can pair up in four different ways: Three of the configurations add up to a total spin of one (a "triplet" state that is only weakly entangled), but the fourth possibility produces a zero spin, or "singlet" state of maximum entanglement, which is crucial for quantum computing.

Next, enzymes break apart the entangled phosphates into two free phosphate ions. Crucially, these remain entangled even as they move apart. This process happens much more quickly, Fisher argues, with the singlet state. These ions can then combine in turn with calcium ions and oxygen atoms to become Posner molecules. Neither the calcium nor the oxygen atoms have a nuclear spin, preserving the one-half total spin crucial for lengthening coherence times. So those clusters protect the entangled pairs from outside interference so that they can maintain coherence for much longer periods of time — Fisher roughly estimates it might last for hours, days or even weeks.

In this way, the entanglement can be distributed over fairly long distances in the brain, influencing the release of neurotransmitters and the firing of synapses between neurons — spooky action at work in the brain.

Testing the Theory

Researchers who work in quantum biology are cautiously intrigued by Fisher's proposal. Alexandra Olaya-Castro(opens a new tab), a physicist at University College London who has worked on quantum photosynthesis, calls it "a well-thought hypothesis. It doesn't give answers, it opens questions that might then lead to how we could test particular steps in the hypothesis." University of Oxford chemist Peter Hore(opens a new tab), who investigates whether migratory birds' navigational systems make use of quantum effects, concurs. "Here's a theoretical physicist who is proposing specific molecules, specific mechanics, all the way through to how this could affect brain activity," he said. "That opens up the possibility of experimental testing."

Experimental testing is precisely what Fisher is now trying to do. He just spent a sabbatical at Stanford University working with researchers there to replicate the 1986 study with pregnant rats. He acknowledged the preliminary results were disappointing, in that the data didn't provide much information, but thinks if it's repeated with a protocol closer to the original 1986 experiment, the results might be more conclusive.

Fisher has applied for funding to conduct further in-depth quantum chemistry experiments. He has cobbled together a small group of scientists from various disciplines at UCSB and the University of California, San Francisco, as collaborators. First and foremost, he would like to investigate whether calcium phosphate really does form stable Posner molecules, and whether the phosphorus nuclear spins of these molecules can be entangled for sufficiently long periods of time.

Even Hore and Olaya-Castro are skeptical of the latter, particularly Fisher's rough estimate that the coherence could last a day or more. "I think it's very unlikely, to be honest," Olaya-Castro said. "The longest time scale relevant for the biochemical activity that's happening here is the scale of seconds, and that's too long." (Neurons can store information for microseconds.) Hore calls the prospect "remote," pegging the limit at one second at best. "That doesn't invalidate the whole idea, but I think he would need a different molecule to get long coherence times," he said. "I don't think the Posner molecule is it. But I'm looking forward to hearing how it goes."

Others see no need to invoke quantum processing to explain brain function. "The evidence is building up that we can explain everything interesting about the mind in terms of interactions of neurons," said Paul Thagard(opens a new tab), a neurophilosopher at the University of Waterloo in Ontario, Canada, to *New Scientist*. (Thagard declined our request to comment further.)

Plenty of other aspects of Fisher's hypothesis also require deeper examination, and he hopes to be able to conduct the experiments to do so. Is the Posner molecule's structure symmetrical? And how isolated are the nuclear spins?

Most important, what if all those experiments ultimately prove his hypothesis wrong? It might be time to give up on the notion of quantum cognition altogether. "I believe that if phosphorus nuclear spin is not being used for quantum processing, then quantum mechanics is not operative in longtime scales in cognition," Fisher said. "Ruling that out is important scientifically. It would be good for science to know."

Q & A

Curious About Consciousness? Ask the Self-Aware Machines

Consciousness is a famously hard problem, so Hod Lipson is starting from the basics: with self-aware robots that can help us understand how we think.

Hod Lipson in the Creative Machines Lab at Columbia University. He's holding the Aracna robot, which is used to test new ideas in locomotion.
Hatnim Lee(opens a new tab) for Quanta Magazine

Introduction

artificial intelligencecomputer scienceconsciousnessmachine learningrobotics All

"Iwant to meet, in my lifetime, an alien species," said Hod Lipson(opens a new tab), a roboticist who runs the Creative Machines Lab at Columbia University. "I want to meet something that is intelligent and not human." But instead of waiting for such beings to arrive, Lipson wants to build them himself — in the form of self-aware machines.

To that end, Lipson openly confronts a slippery concept — consciousness — that often feels verboten among his colleagues. “We used to refer to consciousness as ‘the C-word’ in robotics and AI circles, because we’re not allowed to touch that topic,” he said. “It’s too fluffy, nobody knows what it means, and we’re serious people so we’re not going to do that. But as far as I’m concerned, it’s almost one of the big unanswered questions, on par with origin of life and origin of the universe. What is sentience, creativity? What are emotions? We want to understand what it means to be human, but we also want to understand what it takes to create these things artificially. It’s time to address these questions head-on and not be shy about it.”

One of the basic building blocks of sentience or self-awareness, according to Lipson, is “self-simulation”: building up an internal representation of one’s body and how it moves in physical space, and then using that model to guide behavior. Lipson investigated artificial self-simulation as early as 2006, with a starfish-shaped robot that used evolutionary algorithms (and a few pre-loaded “hints about physics”) to teach itself how to flop forward on a tabletop. But the rise of modern artificial intelligence technology in 2012 (including convolutional neural networks and deep learning) “brought new wind into this whole research area,” he said.

In early 2019, Lipson’s lab revealed a robot arm that uses deep learning to generate its own internal self-model completely from scratch — in a process that Lipson describes as “not unlike a babbling baby observing its hands.” The robot’s self-model lets it accurately execute two different tasks — picking up and placing small balls into a cup, and writing letters with a marker — without requiring specific training for either one. Furthermore, when the researchers simulated damage to the robot’s body by adding a deformed component, the robot detected the change, updated its self-model accordingly, and was able to resume its tasks.

It’s a far cry from robots that think deep thoughts. But Lipson asserts that the difference is merely one of degree. “When you talk about self-awareness, people think the robot is going to suddenly wake up and say, ‘Hello, why am I here?’” Lipson said. “But self-awareness is not a black-and-white thing. It starts from very trivial things like, ‘Where is my hand going to move?’ It’s the same question, just on a shorter time horizon.”

Quanta spoke with Lipson about how to define self-awareness in robots, why it matters, and where it could lead. The interview has been condensed and edited for clarity.

You're clearly interested in big questions about the nature of consciousness — but why are you investigating them through robotics? Why aren't you a philosopher or a neuroscientist?

To me the nice thing about robotics is that it forces you to translate your understanding into an algorithm and into a mechanism. You can't beat around the bush, you can't use empty words, you can't say things like "canvas of reality" that mean different things to different people, because they're too vague to translate into a machine. Robotics forces you to be concrete.

Lipson in his office at Columbia.

I want to build one of these things. I don't want to just talk about it. The philosophers, with all due respect, have not made a lot of progress on this for a thousand years. Not for lack of interest, not for lack of smart people — it's just too hard to approach it from the top down. Neuroscientists have approached this in a more quantitative way. Still, I think they're also hampered by the fact that they're taking a top-down approach.

If you want to understand consciousness, why start with the most complex conscious being — that is, a human? It's like starting uphill, the most difficult way to start. Let's try to look at simpler systems that are potentially easier to understand. That's what we're trying to do: We looked at something very trivial, [a robot] that has four degrees of freedom, and asked, "Can we make this thing self-simulate?"

Are self-simulation and self-awareness the same thing?

A system that can simulate itself is to some degree self-aware. And the degree to which it can simulate itself — the fidelity of that simulation, the short-term or long-term time horizon it can simulate itself within — all these different things factor into how much it is self-aware. That's the basic hypothesis.

So you're reducing a term like "self-awareness" to a more technical definition about self-simulation — the ability to build a virtual model of your own body in space.

Yes, we have a different definition that we use that is very concrete. It's mathematical, you can measure it, you can quantify it, you can compute the error to what degree. Philosophers might say, "Well, that's not how we see self-awareness." Then the discussion usually becomes very vague. You can argue that our definition is not really self-awareness. But we have something that's very grounded and easy to quantify, because we have a benchmark. The benchmark is the traditional, hand-coded self-model that an engineer gives to a robot. With our robot, we wanted to see if an AI algorithm can learn a self-model that's equal or better than what that traditional, coded-by-hand model can do.

Individual particle robots (left) can only expand and contract, yet they can work together as a group to move around and accomplish tasks. Robots designed to explore self-replication (right) can morph into a number of shapes.

Hatnim Lee(opens a new tab) for Quanta Magazine

Why is a physical robot necessary? Why not investigate self-awareness in a disembodied system?

We're looking for a closed system that can potentially simulate itself — and to do that, it needs to have inputs and outputs, but there also has to be a boundary, a place where you draw the "self." A robot is a very natural kind of thing that does that. It has actions, it has sensations, and it has a boundary, so things happen to it and there's something to simulate. I'm a roboticist, it's sort of my first choice.

Did the robot create its self-model from a total blank slate?

We started with absolutely nothing, just as a matter of principle, to see how far we can go. In the previous case [with the starfish-shaped robot], we didn't have the computational horsepower. We had to tell it, "You don't know what you are and where your pieces are, but let me tell you about $F = ma$ and other rules from physics that we know are true, and you take it from there."

How does artificial intelligence play into this?

For some reason, we are very happy to have robots learn about the external world [using artificial intelligence], but when it comes to themselves, for some odd reason, we insist on hand-coding the model. So what we did is actually fairly trivial: We said, "Let's take all that infrastructure that people have made to help robots learn about the world, and we're going to turn it inside, on itself." In one sentence, that's all we did.

Video: The roboticist Hod Lipson, the director of the Creative Machines Lab at Columbia University, uses robots to explore ancient questions about how people think.

Hatnim Lee(opens a new tab) for Quanta Magazine

The robot made 1,000 random movements to gather data for the deep-learning algorithm to create the self-simulation. Is this the process that you describe as being like babbling in a human infant?

That's exactly it. The robot waves around, and it sort of observes where its tip is. Imagine yourself moving your muscles around and watching the tip of your finger. That's your input and output. The robot is out there babbling for 30-odd hours, and once we collect all the data, we can go home. From there on out, it's purely a computational challenge [to learn the self-model].

What we did then is we broke the robot [by adding a deformed part] and did it again. And we saw how the broken robot can start with the intact model and correct it. The second time it learns, it doesn't have to learn from scratch. There is a re-babbling period, but much less than it needed originally — only 10% [of the original period].

But before it even does the re-babbling, it needs to know that something went wrong. That's a very powerful thing. How does it know? When you have a self-model and something goes wrong, you instantly know because if you open your eyes, you'll see your hand is not where it's supposed to be. You're expected to be within four centimeters of the point you wanted it to be, but it is suddenly 16 centimeters away. You get that feedback immediately. So the robot immediately knows there's something wrong. Then it takes it a while to figure out how to compensate, but even knowing that something is wrong is, I think, very important.

These paintings were created by a decommissioned factory robot that was trained to paint using artificial intelligence.
Hatnim Lee(opens a new tab) for Quanta Magazine

Is this self-model analogous to parts of the human brain that act like an internal map of the body?

I think that's what it is. And again, that's why it's so crude and so simple. The fact that our robot was a four-degree-of-freedom arm is what put this within reach. If it were a humanoid that has 800 degrees of freedom, that might have been too complicated for the AI that we have today.

If this really is a form of self-awareness, why should robots have it? What good is it?

It makes robots ultimately much more resilient. You can model robots manually, as we do today, but that's very laborious and it's slowing us down. When a robot in the real world deforms, or breaks, if a wheel falls off or a motor slows down, then suddenly the model is incorrect. And it's not just going to be a factory robot that puts a screw in the wrong place. If you consider driverless cars, we can trust our lives to autonomous robots. This is serious stuff. You want these robots to be able to detect that something has gone wrong and to be able to do that reliably.

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1. A New Approach to Understanding How Machines Think
2. Foundations Built for a General Theory of Neural Networks
3. To Build Truly Intelligent Machines, Teach Them Cause and Effect
4. Smart Swarms Seek New Ways to Cooperate

The other reason is flexibility. Let's say the robot does one task and as it's doing that task, it's continuously updating its self-model. Now if it needs to do a new task — say it needs to put a screw in a different place, or it needs to spray instead of putting screws in — it can use that same self-model to learn and plan how to do that new task. From the outside, it looks like what we call "zero-shot learning," which is one of these things that humans appear to do. You can stare at a tree you've never climbed before and then you can walk up to it and climb it. When the robot can self-model, it can learn internally like that: You don't see that it's been training for hours inside its own internal simulation. All you can see is that it did one task, then it sat there for a while, and suddenly it can do a new task without ever trying.

What's the connection between a robot that can self-simulate its own body and a robot that can have internal "thoughts" — something that sounds more like the informal meaning of "self-awareness"?

We have other projects that we're working on which have to do with self-modeling not the physical body, but the cognitive process. We're taking baby steps in both of these directions. It is completely a leap of faith to believe that eventually this will get to human-level cognition and beyond.

So you're hypothesizing that those two paths — self-simulating the body, and self-simulating the mind itself — will converge?

Exactly. I think it's all the same thing. That's our hypothesis, and we'll see how far we can push it.

C O N S C I O U S N E S S

A Theory of Reality as More Than the Sum of Its Parts

New math shows how, contrary to conventional scientific wisdom, conscious beings and other macroscopic entities might have greater influence over the future than does the sum of their microscopic components.

Introduction

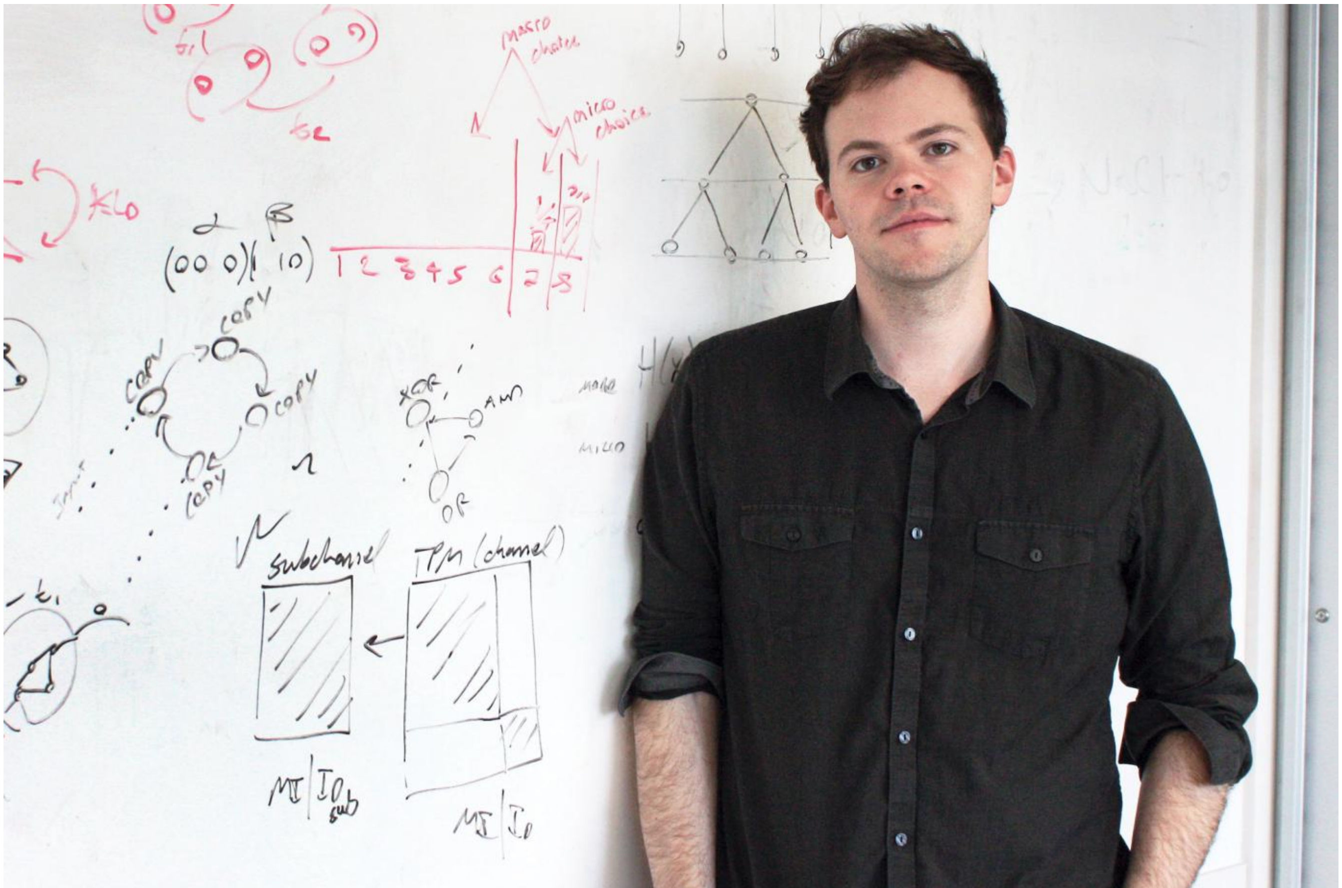
In his 1890 opus, *The Principles of Psychology*, William James invoked Romeo and Juliet to illustrate what makes conscious beings so different from the particles that make them up.

"Romeo wants Juliet as the filings want the magnet; and if no obstacles intervene he moves towards her by as straight a line as they," James wrote. "But Romeo and Juliet, if a wall be built between them, do not remain idiotically pressing their faces against its opposite sides like the magnet and the filings. ... Romeo soon finds a circuitous way, by scaling the wall or otherwise, of touching Juliet's lips directly."

Erik Hoel(opens a new tab), a 29-year-old theoretical neuroscientist and writer, quoted the passage in a recent essay(opens a new tab) in which he laid out his new mathematical explanation of how consciousness and agency arise. The existence of agents — beings with intentions and goal-oriented behavior — has long seemed profoundly at odds with the reductionist assumption that all behavior arises from mechanistic interactions between particles. Agency doesn't exist among the atoms, and so reductionism suggests agents don't exist at all: that Romeo's desires and psychological states are not the real causes of his actions, but merely approximate the unknowably complicated causes and effects between the atoms in his brain and surroundings.

Hoel's theory, called "causal emergence," roundly rejects this reductionist assumption.

"Causal emergence is a way of claiming that your agent description is really real," said Hoel, a postdoctoral researcher at Columbia University who first proposed the idea(opens a new tab) with Larissa Albantakis and Giulio Tononi(opens a new tab) of the University of Wisconsin, Madison. "If you just say something like, ‘Oh, my atoms made me do it’ — well, that might not be true. And it might be provably not true.”



Erik Hoel, a theoretical neuroscientist at Columbia University.
Julia Buntaine

Using the mathematical language of information theory, Hoel and his collaborators claim to show that new causes — things that produce effects — can emerge at macroscopic scales. They say coarse-grained macroscopic states of a physical system (such as the psychological state of a brain) can have more causal power over the system’s future than a more detailed, fine-grained description of the system possibly could. Macroscopic states, such as desires or beliefs, “are not just shorthand for the real causes,” explained Simon DeDeo(opens a new tab), an information theorist and cognitive scientist at Carnegie Mellon University and the Santa Fe Institute who is not involved in the work, “but it’s actually a description of the real causes, and a more fine-grained description would actually miss those causes.”

“To me, that seems like the right way to talk about it,” DeDeo said, “because we do want to attribute causal properties to higher-order events [and] things like mental states.”

Hoel and collaborators have been developing the mathematics behind their idea since 2013. In a May paper(opens a new tab) in the journal *Entropy*, Hoel placed causal emergence on a firmer theoretical footing by showing that macro scales gain causal power in exactly the same way, mathematically, that error-correcting codes increase the amount of information that can be sent over information channels. Just as codes reduce noise (and thus uncertainty) in transmitted data — Claude Shannon’s 1948 insight that formed the bedrock of information theory — Hoel claims that macro states also reduce noise and uncertainty in a system’s causal structure, strengthening causal relationships and making the system’s behavior more deterministic.
“I think it’s very significant,” George Ellis(opens a new tab), a South African cosmologist who has also written about top-down causation(opens a new tab) in nature, said of Hoel’s new paper. Ellis thinks causal emergence could account for many emergent phenomena such as superconductivity and topological phases of matter. Collective systems like bird flocks and superorganisms — and even simple structures like crystals and waves — might also exhibit causal emergence, researchers said.

The work on causal emergence is not yet widely known among physicists, who for centuries have taken a reductionist view of nature and largely avoided further philosophical thinking on the matter. But at the interfaces between physics, biology, information theory and philosophy, where puzzles crop up, the new ideas have generated excitement. Their ultimate usefulness in explaining the world and its mysteries — including consciousness, other kinds of emergence, and the relationships between the micro and macro levels of reality — will come down to whether Hoel has nailed the notoriously tricky notion of causation: Namely, what’s a cause? “If you brought 20 practicing scientists into a room and asked what causation was, they would all disagree,” DeDeo said. “We get mixed up about it.”

A Theory of Cause

In a fatal drunk driving accident, what’s the cause of death? Doctors name a ruptured organ, while a psychologist blames impaired decision-making abilities and a sociologist points to permissive attitudes toward alcohol. Biologists, chemists and physicists, in turn, see ever more elemental causes.

“Famously, Aristotle had a half-dozen notions of causes,” DeDeo said. “We as scientists have rejected all of them except things being in literal contact, touching and pushing.”

The true causes, to a physicist, are the fundamental forces acting between particles; all effects ripple out from there. Indeed, these forces, when they can be isolated, appear perfectly deterministic and reliable — physicists can predict with high precision the outcomes of particle collisions at the Large Hadron Collider, for instance. In this view, causes and effects become hard to predict from first principles only when there are too many variables to track.

It’s a bit of a bold thing to do to talk about the mathematics of causation.

Simon DeDeo

Furthermore, philosophers have argued that causal power existing at two scales at once would be twice what the world needs; to avoid double-counting, the “exclusion argument” says all causal power must originate at the micro level. But it’s almost always easier to discuss causes and effects in terms of macroscopic entities. When we look for the cause of a fatal car crash, or Romeo’s decision to start climbing, “it doesn’t seem right to go all the way down to microscopic scales of neurons firing,” DeDeo said. “That’s where Erik [Hoel] is jumping in. It’s a bit of a bold thing to do to talk about the mathematics of causation.”

Friendly and large-limbed, Hoel grew up reading books at Jabberwocky, his family’s bookstore in Newburyport, Massachusetts. He studied creative writing as an undergraduate and planned to become a writer. (He still writes fiction(opens a new tab) and has started a novel.) But he was also drawn to the question of consciousness — what it is, and why and how we have it — because he saw it as an immature scientific subject that allowed for creativity. For graduate school, he went to Madison, Wisconsin, to work with Tononi — the only person at the time, in Hoel’s view, who had a truly scientific theory of consciousness.

Tononi conceives of consciousness as information: bits that are encoded not in the states of individual neurons, but in the complex networking of neurons, which link together in the brain into larger and larger ensembles. Tononi argues that this special “integrated information” corresponds to the unified, integrated state that we experience as subjective awareness. Integrated information theory has gained prominence in the last few years, even as debates have ensued about whether it is an accurate and sufficient proxy for consciousness. But when Hoel first got to Madison in 2010, only the two of them were working on it there.

Giulio Tononi, a neuroscientist and psychiatrist at the University of Wisconsin, Madison, best known for his research on sleep and consciousness.
John Maniaci/UW Health

Tononi tasked Hoel with exploring the general mathematical relationship between scales and information. The scientists later focused on how the amount of integrated information in a neural network changes as you move up the hierarchy of spatiotemporal scales, looking at links between larger and larger groups of neurons. They hoped to figure out which ensemble size might be associated with maximum integrated information — and thus, possibly, with conscious thoughts and decisions. Hoel taught himself information theory and plunged into the philosophical debates around consciousness, reductionism and causation.

Hoel soon saw that understanding how consciousness emerges at macro scales would require a way of quantifying the causal power of brain states. He realized, he said, that "the best measure of causation is in bits." He also read the works of the computer scientist and philosopher Judea Pearl(opens a new tab), who developed a logical language for studying causal relationships in the 1990s called causal calculus. With Albantakis and Tononi, Hoel formalized a measure of causal power called "effective information," which indicates how effectively a particular state influences the future state of a system. (Effective information can be used to help calculate integrated information, but it is simpler and more general and, as a measure of causal power, does not rely on Tononi's other ideas about consciousness.)

The researchers showed that in simple models of neural networks, the amount of effective information increases as you coarse-grain over the neurons in the network — that is, treat groups of them as single units. The possible states of these interlinked units form a causal structure, where transitions between states can be mathematically modeled using so-called Markov chains. At a certain macroscopic scale, effective information peaks: This is the scale at which states of the system have the most causal power, predicting future states in the most reliable, effective manner. Coarse-grain further, and you start to lose important details about the system's causal structure. Tononi and colleagues hypothesize that the scale of peak causation should correspond, in the brain, to the scale of conscious decisions; based on brain imaging studies, Albantakis guesses that this might happen at the scale of neuronal microcolumns, which consist of around 100 neurons.

Causation is what you need to give structure to the universe.

Larissa Albantakis

Causal emergence is possible, Hoel explained, because of the randomness and redundancy that plagues the base scale of neurons. As a simple example, he said to imagine a network consisting of two groups of 10 neurons each. Each neuron in group A is linked to several neurons in group B, and when a neuron in group A fires, it usually causes one of the B neurons to fire as well. Exactly which linked neuron fires is unpredictable. If, say, the state of group A is {1,0,0,1,1,1,0,1,1,0}, where 1s and 0s represent neurons that do and don't fire, respectively, the resulting state of group B can have myriad possible combinations of 1s and 0s. On average, six neurons in group B will fire, but which six is nearly random; the micro state is hopelessly indeterministic. Now, imagine that we coarse-grain over the system, so that this time, we group all the A neurons together and simply count the total number that fire. The state of group A is {6}. This state is highly likely to lead to the state of group B also being {6}. The macro state is more reliable and effective; calculations show it has more effective information.

A real-world example cements the point. "Our life is very noisy," Hoel said. "If you just give me your atomic state, it may be totally impossible to guess where your future [atomic] state will be in 12 hours. Try running that forward; there's going to be so much noise, you'd have no idea. Now give a psychological description, or a physiological one: Where are you going to be in 12 hours?" he said (it was mid-day). "You're going to be asleep — easy. So these higher-level relationships are the things that seem reliable. That would be a super simple example of causal emergence."

For any given system, effective information peaks at the scale with the largest and most reliable causal structure. In addition to conscious agents, Hoel says this might pick out the natural scales of rocks, tsunamis, planets and all other objects that we normally notice in the world. "And the reason why we're tuned into them evolutionarily [might be] because they are reliable and effective, but that also means they are causally emergent," Hoel said.

Brain-imaging experiments are being planned in Madison and New York, where Hoel has joined the lab of the Columbia neuroscientist Rafael Yuste(opens a new tab). Both groups will examine the brains of model organisms to try to home in on the spatiotemporal scales that have the most causal control over the future. Brain activity at these scales should most reliably predict future activity. As Hoel put it, "Where does the causal structure of the brain pop out?" If the data support their hypothesis, they'll see the results as evidence of a more general fact of nature. "Agency or consciousness is where this idea becomes most obvious," said William Marshall, a postdoctoral researcher in the Wisconsin group. "But if we do find that causal emergence is happening, the reductionist assumption would have to be re-evaluated, and that would have to be applied broadly."

New Philosophical Thinking

Sara Walker(opens a new tab), a physicist and astrobiologist at Arizona State University who studies the origins of life, hopes measures like effective information and integrated information will help define what she sees as the gray scale leading between nonlife and life (with viruses and cell cycles somewhere in the gray area). Walker has been collaborating with Tononi's team on studies of real and artificial cell cycles, with preliminary indications that integrated information might correlate with being alive.

A Fundamental Theory to Model the Mind

Support is growing for a decades-old physics idea suggesting that localized episodes of disordered brain activity help keep the overall system in healthy balance.

Mounting evidence suggests that localized episodes of disordered brain activity, like avalanches in a sand pile, help keep the overall system in healthy balance.
James O'Brien for Quanta Magazine

In 1999, the Danish physicist Per Bak proclaimed to a group of neuroscientists that it had taken him only 10 minutes to determine where the field had gone wrong. Perhaps the brain was less complicated than they thought, he said. Perhaps, he said, the brain worked on the same fundamental principles as a simple sand pile, in which avalanches of various sizes help keep the entire system stable overall — a process he dubbed “self-organized criticality.”

As much as scientists in other fields adore outspoken, know-it-all physicists, Bak’s audacious idea — that the brain’s ordered complexity and thinking ability arise spontaneously from the disordered electrical activity of neurons — did not meet with immediate acceptance.

But over time, in fits and starts, Bak’s radical argument has grown into a legitimate scientific discipline. Now, about 150 scientists worldwide investigate so-called “critical” phenomena in the brain, the topic of at least three focused workshops in 2013 alone. Add the ongoing efforts to found a journal devoted to such studies, and you have all the hallmarks of a field moving from the fringes of disciplinary boundaries to the mainstream.

How do we know that the creations of worlds are not determined by falling grains of sand?

Victor Hugo, *Les Misérables*

In the 1980s, Bak first wondered how the exquisite order seen in nature arises out of the disordered mix of particles that constitute the building blocks of matter. He found an answer in phase transition, the process by which a material transforms from one phase of matter to another. The change can be sudden, like water evaporating into steam, or gradual, like a material becoming superconductive. The precise moment of transition — when the system is halfway between one phase and the other — is called the critical point, or, more colloquially, the “tipping point.”

Classical phase transitions require what is known as precise tuning: in the case of water evaporating into vapor, the critical point can only be reached if the temperature and pressure are just right. But Bak proposed a means by which simple, local interactions between the elements of a system could spontaneously reach that critical point — hence the term self-organized criticality.

Think of sand running from the top of an hourglass to the bottom. Grain by grain, the sand accumulates. Eventually, the growing pile reaches a point where it is so unstable that the next grain to fall may cause it to collapse in an avalanche. When a collapse occurs, the base widens, and the sand starts to pile up again — until the mound once again hits the critical point and founders. It is through this series of avalanches of various sizes that the sand pile — a complex system of millions of tiny elements — maintains overall stability.

While these small instabilities paradoxically keep the sand pile stable, once the pile reaches the critical point, there is no way to tell whether the next grain to drop will cause an avalanche — or just how big any given avalanche will be. All one can say for sure is that smaller avalanches will occur more frequently than larger ones, following what is known as a power law.

Bak introduced self-organized criticality in a landmark 1987 paper(opens a new tab) — one of the most highly cited physics papers of the last 30 years. Bak began to see the stabilizing role of frequent smaller collapses wherever he looked. His 1996 book, "How Nature Works," extended the concept beyond simple sand piles to other complex systems: earthquakes, financial markets, traffic jams, biological evolution, the distribution of galaxies in the universe — and the brain. Bak's hypothesis implies that most of the time, the brain teeters on the edge of a phase transition, hovering between order and disorder.

The brain is an incredibly complex machine. Each of its tens of billions of neurons is connected to thousands of others, and their interactions give rise to the emergent process we call "thinking." According to Bak, the electrical activity of brain cells shift back and forth between calm periods and avalanches — just like the grains of sand in his sand pile — so that the brain is always balanced precariously right at that the critical point.

A better understanding of these critical dynamics could shed light on what happens when the brain malfunctions. Self-organized criticality also holds promise as a unifying theoretical framework. According to the neurophysiologist Dante Chialvo(opens a new tab), most of the current models in neuroscience apply only to single experiments; to replicate the results from other experiments, scientists must change the parameters — tune the system — or use a different model entirely.

Per Bak at Rockefeller University in 1998.
Courtesy of Dante Chialvo

Self-organized criticality has a certain intuitive appeal. But a good scientific theory must be more than elegant and beautiful. Bak's notion has had its share of critics, in part because his approach strikes many as ridiculously broad: He saw nothing strange about leaping across disciplinary boundaries and using self-organized criticality to link the dynamics of forest fires, measles and the large-scale structure of the universe — often in a single talk. Nor was he one to mince words.

His abrasive personality did not endear him to his critics, although Lee Smolin(opens a new tab), a physicist at the Perimeter Institute for Theoretical Physics, in Canada, has chalked this up to "childlike simplicity," rather than arrogance. "It would not have occurred to him that there was any other way to be," Smolin wrote in a remembrance after Bak's death in 2002(opens a new tab). "Science is hard, and we have to say what we think."

Nonetheless, Bak's ideas found fertile ground in a handful of like-minded scientists. Chialvo, now with the University of California, Los Angeles, and with the National Scientific and Technical Research Council in Argentina, met Bak at Brookhaven National Laboratory around 1990 and became convinced that self-organized criticality could explain brain activity. He, too, encountered considerable resistance. "I had to put up with a number of critics because we didn't have enough data," Chialvo said. Dietmar Plenz(opens a new tab), a neuroscientist with the National Institute of Mental Health, recalled that it was impossible to win a grant in neuroscience to work on self-organized criticality at the time, given the lack of experimental evidence.

Since 2003, however, the body of evidence showing that the brain exhibits key properties of criticality has grown, from examinations of slices of cortical tissue and electroencephalography (EEG) recordings of the interactions between individual neurons to large-scale studies comparing the predictions of computer models with data from functional magnetic resonance (fMRI) imaging. "Now the field is mature enough to stand up to any fair criticism(opens a new tab)," Chialvo said.

One of the first empirical tests of Bak's sand pile model took place in 1992(opens a new tab), in the physics department of the University of Oslo. The physicists confined piles of rice between glass plates and added grains one at a time, capturing the resulting avalanche dynamics on camera. They found that the piles of elongated grains of rice behaved much like Bak's simplified model.

Most notably, the smaller avalanches were more frequent than the larger ones, following the expected power law distribution. That is, if there were 100 small avalanches involving only 10 grains during a given time frame, there would be 10 avalanches involving 100 grains in the same period, but only a single large avalanche involving 1,000 grains. (The same pattern had been observed in earthquakes and their aftershocks. If there are 100 quakes measuring 6.0 on the Gutenberg-Richter scale in a given year, there will be 10 7.0 quakes and one 8.0 quake.)

Chialvo envisions self-organized criticality providing a broader, more fundamental theory for neuroscientists, like those found in physics.

Ten years later, Plenz and a colleague, John Beggs(opens a new tab), now a biophysicist at Indiana University, observed the same pattern of avalanches(opens a new tab) in the electrical activity of neurons in cortical slices — the first key piece of evidence that the brain functions at criticality. "It was something that no one believed the brain would do," Plenz said. "The surprise is that is exactly what happens." Studies using magnetoencephalography(opens a new tab) (MEG) and Chialvo's own work(opens a new tab) comparing computer simulations with fMRI imaging data of the brain's resting state have since added to the evidence that the brain exhibits these key avalanche dynamics.

But perhaps it is not so surprising. There can be no phase transitions without a critical point, and without transitions, a complex system — like Bak's sand pile, or the brain — cannot adapt. That is why avalanches only show up at criticality, a "sweet spot" where a system is perfectly balanced between order and disorder, according to Plenz. They typically occur when the brain is in its normal resting state. Avalanches are a mechanism by which a complex system avoids becoming trapped, or "phase-locked," in one of two extreme cases. At one extreme, there is too much order, such as during an epileptic seizure; the interactions among elements are too strong and rigid, so the system cannot adapt to changing conditions. At the other, there is too much disorder; the neurons aren't communicating as much, or aren't as broadly interconnected throughout the brain, so information can't spread as efficiently and, once again, the system is unable to adapt.

A complex system that hovers between "boring randomness and boring regularity" is surprisingly stable overall, said Olaf Sporns(opens a new tab), a cognitive neuroscientist at Indiana University. "Boring is bad," he said, at least for a critical system. In fact, "if you try to avoid ever sparking an avalanche, eventually when one does occur, it is likely to be really large," said Raissa D'Souza(opens a new tab), a complex systems scientist at the University of California, Davis, who simulated just such a generic system last year. "If you spark avalanches all the time, you've used up all the fuel, so to speak, and so there is no opportunity for large avalanches."

D'Souza's research(opens a new tab) applies these dynamics to better understand power outages across the electrical grid. The brain, too, needs sufficient order to function properly, but also enough flexibility to adapt to changing conditions; otherwise, the organism could not survive. This could be one reason that the brain exhibits hallmarks of self-organized criticality: It confers an evolutionary advantage. "A brain that is not critical is a brain that does exactly the same thing every minute, or, in the other extreme, is so chaotic that it does a completely random thing, no matter what the circumstances," Chialvo said. "That is the brain of an idiot."

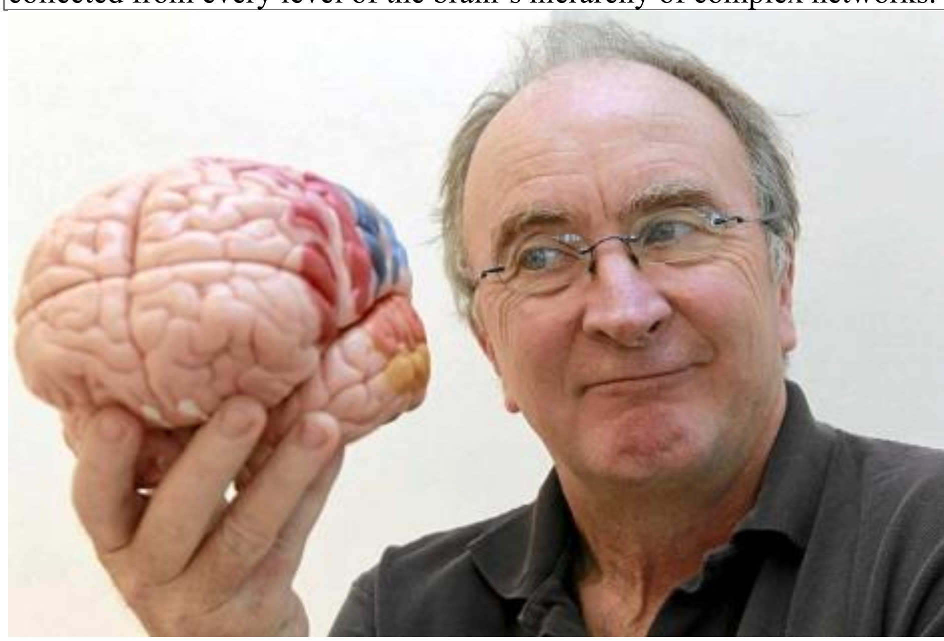
From left: Kim Christensen, Dante Chialvo, Per Bak and Zeev Olami at Brookhaven National Laboratory in the early 1990s.
Courtesy of Dante Chialvo

When the brain veers away from criticality, information can no longer percolate through the system as efficiently. One study (not yet published) examined sleep deprivation; subjects remained awake for 36 hours and then took a reaction time test while an EEG monitored their brain activity. The more sleep-deprived the subject, the more the person's brain activity veered away from the critical balance point and the worse the performance on the test.

Another study(opens a new tab) collected data from epileptic subjects during seizures. The EEG recordings revealed that mid-seizure, the telltale avalanches of criticality vanished. There was too much synchronization among neurons, and then, Plenz said, "information processing breaks down, people lose consciousness, and they don't remember what happened until they recover."

Chialvo envisions self-organized criticality providing a broader, more fundamental theory for neuroscientists, like those found in physics. He believes it could be used to model the mind in all its possible states: awake, asleep, under anesthesia, suffering a seizure, and under the influence of a psychedelic drug, among many others.

This is especially relevant as neuroscience moves deeper into the realm of big data. The latest advanced imaging techniques are capable of mapping synapses and monitoring brain activity at unprecedented resolutions, with a corresponding explosion in the size of data sets. Billions of dollars in research funding has launched the Human Connectome Project(opens a new tab) — which aims to build a "network map" of neural pathways in the brain — and the Brain Research Through Advancing Innovative Neurotechnologies(opens a new tab) (BRAIN), dedicated to developing new technological tools for recording signals from cells. There is also Europe's Human Brain Project(opens a new tab), working to simulate the complete human brain on a supercomputer, and China's Brainnetome(opens a new tab) project to integrate data collected from every level of the brain's hierarchy of complex networks.



Dante Chialvo during an interview with the Spanish newspaper El Mundo in 2011.
Pep Vicens

But without an underlying theory, it will be difficult to glean all the potential insights hidden in the data. "It is fine to build maps and it is fine to catalog pieces and how they are related, so long as you don't lose track of the fact that when the system you map actually functions, it is in an integrated system and it is dynamic," Sporns said.

"The structure of the brain — the precise map of who connects with whom — is almost irrelevant by itself," Chialvo said — or rather, it is necessary but not sufficient to decipher how cognition and behavior are generated in the brain. "What is relevant is the dynamics," Chialvo said. He then compared the brain with a street map of Los Angeles containing details of all the connections at every scale, from private driveways to public freeways. The map tells us only about the structural connections; it does not help predict how traffic moves along those connections or where (and when) a traffic jam is likely to form. The map is static; traffic is dynamic. So, too, is the activity of the brain. In recent work, Chialvo said, researchers have demonstrated that both traffic dynamics and brain dynamics exhibit criticality.

Sporns emphasizes that it remains to be seen just how robust this phenomenon might be in the brain, pointing out that more evidence is needed beyond the observation of power laws in brain dynamics. In particular, the theory still lacks a clear description for how criticality arises from neurobiological mechanisms — the signaling of neurons in local and distributed circuits. But he admits that he is rooting for the theory to succeed. “It makes so much sense,” he said. “If you were to design a brain, you would probably want criticality in the mix. But ultimately, it is an empirical question.”

A Private View of Quantum Reality

Quantum theorist Christopher Fuchs explains how to solve the paradoxes of quantum mechanics. His price: physics gets personal.

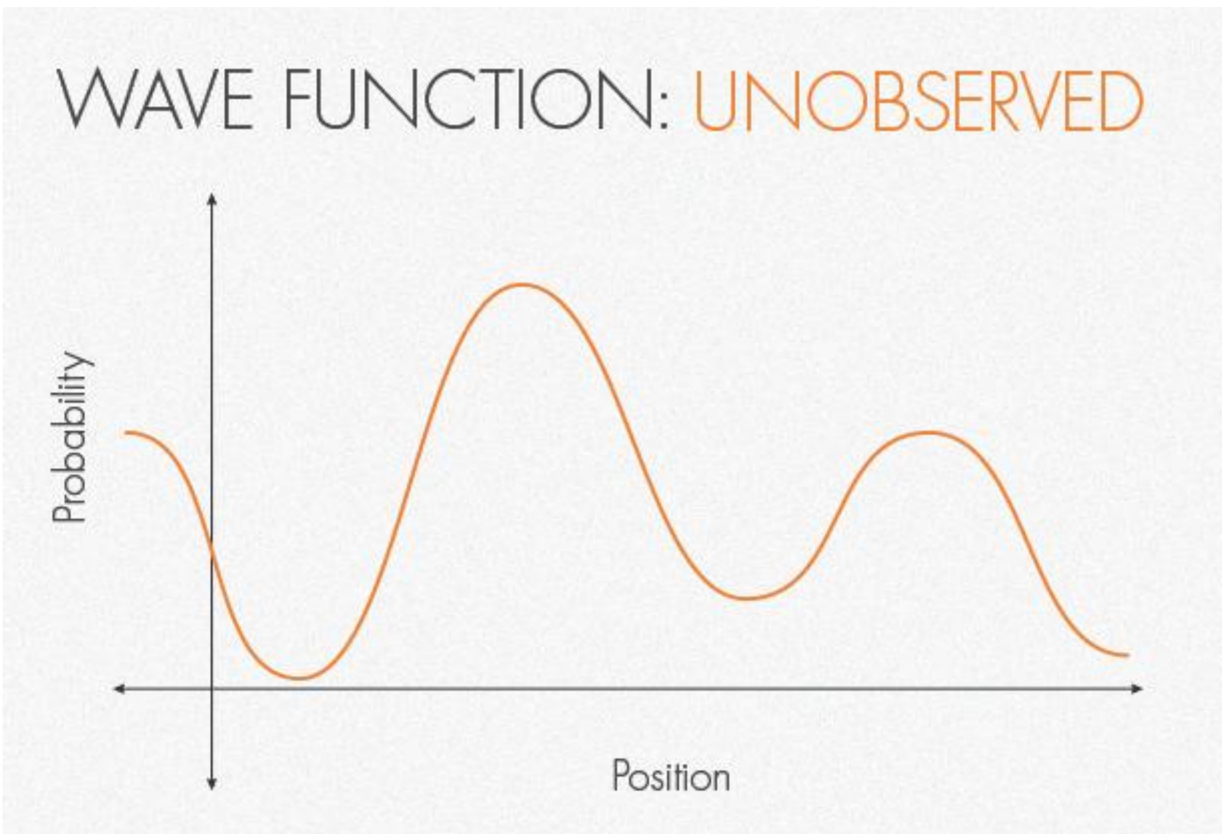
Christopher Fuchs is the developer and main proponent of QBism, an alternative interpretation of quantum mechanics that treats the quantum wave function as a reflection of ignorance.
Katherine Taylor for Quanta Magazine

Christopher Fuchs(opens a new tab) describes physics as “a dynamic interplay between storytelling and equation writing. Neither one stands alone, not even at the end of the day.” And indeed Fuchs, a physicist at the University of Massachusetts, Boston, has a radical story to tell. The story is called QBism, and it goes something like this.

Once upon a time there was a wave function, which was said to completely describe the state of a physical system out in the world. The shape of the wave function encodes the probabilities for the outcomes of any measurements an observer might perform on it, but the wave function belonged to nature itself, an objective description of an objective reality.

Then Fuchs came along. Along with the researchers Carlton Caves(opens a new tab) and Rüdiger Schack(opens a new tab), he interpreted the wave function’s probabilities as Bayesian probabilities — that is, as subjective degrees of belief about the system. Bayesian probabilities could be thought of as gambling attitudes for placing bets on measurement outcomes, attitudes that are updated as new data come to light. In other words, Fuchs argued, the wave function does not describe the world — it describes the observer. “Quantum mechanics,” he says, “is a law of thought.”

Quantum Bayesianism, or QBism as Fuchs now calls it, solves many of quantum theory's deepest mysteries. Take, for instance, the infamous "collapse of the wave function," wherein the quantum system inexplicably transitions from multiple simultaneous states to a single actuality. According to QBism, the wave function's "collapse" is simply the observer updating his or her beliefs after making a measurement. Spooky action at a distance, wherein one observer's measurement of a particle right here collapses the wave function of a particle way over there, turns out not to be so spooky — the measurement here simply provides information that the observer can use to bet on the state of the distant particle, should she come into contact with it. But how, we might ask, does her measurement here affect the outcome of a measurement a second observer will make over there? In fact, it doesn't. Since the wavefunction doesn't belong to the system itself, each observer has her own. My wavefunction doesn't have to align with yours.



A quantum particle can be in a range of possible states. When an observer makes a measurement, she instantaneously "collapses" the wave function into one possible state. QBism argues that this collapse isn't mysterious. It just reflects the updated knowledge of the observer. She didn't know where the particle was before the measurement. Now she does.
Olena Shmahalo/Quanta Magazine

In a sea of interpretations of quantum weirdness, QBism swims alone. The traditional "Copenhagen interpretation" treats the observer as somehow standing outside of nature, imbued with mysterious wave-function-collapsing powers, governed by laws of physics that are different from those that govern what's being observed. That's all well and good until a second observer comes along to observe the first observer. The "many worlds" interpretation claims that the universe and all of its observers are described by a single, giant wave function that never collapses. Of course, to make that work, one must insist that at every fork in the road — every coin toss, every decision, every moment — the wave function branches and so do we, splitting into countless versions of ourselves who have collectively done and not done everything we'll ever do or not do. For those to whom a set of infinite parallel realities is too high a price to pay to avoid wave-function collapse, there's always the Bohmian interpretation, which seeks to restore a more concrete reality to the world by postulating the existence of a guiding force that permeates the universe and deterministically governs everything in it. Unfortunately, this new reality lies forever out of reach of scientific probing.

Those interpretations all have something in common: They treat the wave function as a description of an objective reality shared by multiple observers. QBism, on the other hand, treats the wave function as a description of a single observer's subjective knowledge. It resolves all of the quantum paradoxes, but at the not insignificant cost of anything we might call "reality." Then again, maybe that's what quantum mechanics has been trying to tell us all along — that a single objective reality is an illusion.

QBism also raises a host of new and equally mysterious questions. If the wave function describes an observer, does the observer have to be human? Does that observer have to have consciousness? Could it be a dog? ("Dogs don't use wave functions," Fuchs said. "Heck, I didn't collapse a wave function until I was 34.") If my wave function doesn't have to align with yours, do we live in the same universe? And if quantum mechanics doesn't describe an external reality, what does?

Fuchs struggles with these questions, often working through his thoughts in the form of emails. His missives have become legendary. For two decades Fuchs has compiled them into huge documents — he calls them his samizdats — which have made the rounds among quantum physicists and philosophers as a kind of underground manuscript. After Fuchs lost his Los Alamos home to a fire in May 2000, he decided to back them up by posting them on the scientific preprint site arxiv.org as a massive paper(opens a new tab), which was later published by Cambridge University Press as a 500-page book(opens a new tab). A second samizdat(opens a new tab) was released 13 years later with an additional 2,300 pages. The emails reveal both Fuchs' searching mind and his colorful character. As the physicist David Mermin(opens a new tab) puts it, "If Chris Fuchs did not exist then God would have been remiss in not inventing him."

So how will the QBism story end? Ultimately, Fuchs wants to answer a single question, one famously asked by the eminent physicist John Archibald Wheeler(opens a new tab), who was Fuchs' mentor: Why the quantum? That is, why should the world be built in such a way that it can only be described by the strange rules of quantum mechanics?

In the meantime, *Quanta* caught up with Fuchs at a coffee shop in Cambridge, Massachusetts, to ask him some questions of our own. An edited and condensed version of our conversation follows.

QUANTA MAGAZINE: You've said, "I knew I had to become a physicist, not for the love of physics, but for the distrust of it."

CHRISTOPHER FUCHS: I was a big science fiction fan when I was a kid. I grew up in a small town in Texas and I really enjoyed the idea of space flight. It seemed inevitable — we were going to the moon, that was just the first step, science is limitless and eventually we'd be doing the things they do in *Star Trek*: go to planets, find new creatures, have adventures. So I started reading books about physics and space travel, and it was there that I first learned that space travel would be difficult because of the great distances between stars. How do you get around this? I learned about John Wheeler and black holes and wormholes, and that possibly wormholes could be a way to get around the speed-limit problem, or we could get past the speed limit using exotic particles called tachyons. I ate the stuff up. Most of it turned out to be pretty improbable; wormholes had proven to be unstable and nobody really believed in tachyons. Overall, the message to me was that physics wouldn't allow us to get to the stars. As a bit of a joke, I would tell my friends, if the laws of physics won't allow us to go to the stars, the laws of physics must be wrong!

Probability does not exist! It will go the way of phlogiston, witches, elves and fairies.

You ended up studying with John Wheeler.

The first time I went to the University of Texas, it dawned on me that the guy I'd read about years before, John Wheeler, was actually a professor there. So I went and read some of his newer papers, in which he was talking about "law without law." He'd say things like, "In the end, the only law is that there is no law." There's no ultimate law of physics. All the laws of physics are mutable and that mutability itself is a principle of physics. He'd say, there's no law of physics that hasn't been transcended. I saw this, and I remembered my joke about how the laws of physics must be wrong, and I was immensely attracted to this idea that maybe ultimately there actually are no laws of physics. What there is in place of laws, I didn't know. But if the laws weren't 100 percent trustworthy, maybe there was a back door to the stars. It was all youthful romanticism; I hadn't even had a physics course yet.

In one of your papers, you mention that Erwin Schrödinger wrote about the Greek influence on our concept of reality, and that it's a historical contingency that we speak about reality without including

the subject — the person doing the speaking. Are you trying to break the spell of Greek thinking?

Schrödinger thought that the Greeks had a kind of hold over us — they saw that the only way to make progress in thinking about the world was to talk about it without the "knowing subject" in it. QBism goes against that strain by saying that quantum mechanics is not about how the world is without us; instead it's precisely about us in the world. The subject matter of the theory is not the world or us but us-within-the-world, the interface between the two.

It's so ingrained in us to think about the world without thinking of ourselves in it. It reminds me of Einstein questioning space and time — these features of the world that seemed so absolute that no one even thought to question them.

It's said that in earlier civilizations, people didn't quite know how to distinguish between objective and subjective. But once the idea of separating the two gained a toehold, we were told that we have to do this, and that science is about the objective. And now that it's done, it's hard to turn back. I think the biggest fear people have of QBism is precisely this: that it's anthropocentric. The feeling is, we got over that with Copernicus, and this has got to be a step backwards. But I think if we really want a universe that's rife with possibility with no ultimate limits on it, this is exactly where you've got to go.

How does QBism get you around those limits?

One way to look at it is that the laws of physics aren't about the stuff "out there." Rather, they are our best expressions, our most inclusive statements, of what our own limitations are. When we say the speed of light is the ultimate speed limit, we're saying that *we* can't go beyond the speed of light. But just as our brains have gotten bigger through Darwinian evolution, one can imagine that eventually we'll have evolved to a stage where we can take advantage of things that we can't now. We might call those things "changes in the laws of physics." Usually we think of the universe as this rigid thing that can't be changed. Instead, methodologically we should assume just the opposite: that the universe is before us so that we can shape it, that it can be changed, and that it will push back on us. We'll understand our limits by noticing how much it pushes back on us.

Let's talk about probability.

Probability does not exist! Bruno de Finetti(opens a new tab), in the intro to his two-volume set on probability theory, writes in all-capital letters, "PROBABILITY DOES NOT EXIST." He says it will go the way of phlogiston, witches, elves and fairies.

When the founders of quantum mechanics realized that the theory describes the world in terms of probabilities, they took that to mean that the world itself is probabilistic.

In Pierre-Simon Laplace's day, probability was thought of as a subjective statement — you don't know everything, but you can manage by quantifying your knowledge. But sometime in the late 1800s and early 1900s, probabilities started cropping up in ways that appeared objective. People were using statistical methods to derive things that could be measured in the laboratory — things like heat. So people figured, if this quantity arises because of probabilistic considerations, and it's objective, it must be that the probabilities are objective as well. Then quantum mechanics came along. The Copenhagen crowd was arguing that quantum mechanics is a complete theory, finished, closed, which was often taken to mean that all of its features should be objective features of nature. If quantum states give probabilities, those probabilities should also be objective features of nature. On the other side of the fence was Albert Einstein, who said quantum mechanics is not complete. When he described probabilities in quantum mechanics, he seemed to interpret them as statements of incomplete knowledge, subjective states.

So when you say that probability doesn't exist, you mean that objective probability doesn't exist.

Right, it doesn't exist as something out in the world without a gambling agent. But suppose you've convinced yourself that the right way to understand probability is as a description of uncertainty and ignorance. Now there's a spectrum of positions you could take. According to the Bayesian statistician I.J. Good, there are 46,656 varieties. When we started working on quantum Bayesianism, we tried to take a stance on probability that was like E.T. Jaynes(opens a new tab)' stance: We'll admit that probabilities are in our heads — my probabilities are in my head, your probabilities are in your head — but if I base my probabilities on the same information that you base yours on, our two probability assignments should be the same. Conditioned on the information, they should be objective. In the spectrum of 46,656 varieties, this stance is called "objective Bayesianism."

At the other end of the spectrum is Bruno de Finetti. He says there's no reason whatsoever for my probabilities and yours to match, because mine are based on my experience and yours are based on your experience. The best we can do, in that case, if we think of probabilities as gambling attitudes, is try to make all of our personal gambling attitudes internally consistent. I should do that with mine, and you with yours, but that's the best we can do. That's what de Finetti meant when he said probability does not exist. He meant, let's take the extreme stance. Instead of saying probabilities are mostly in my head but there are some extra rules that still anchor them to the world, he got rid of the anchor.

Eventually my colleague Rüdiger Schack and I felt that to be consistent we had to break the ties with Jaynes and move more in the direction of de Finetti. Where Jaynes made fun of de Finetti, we thought, actually, that's where the real solution lies.

Is that when the name changed from quantum Bayesianism to QBism?

Quantum Bayesianism was too much of a mouthful, so I started calling it QBism. As soon as I started calling it QBism, people paid more attention to it! But my colleague David Mermin started complaining that QBism really shouldn't be short for quantum Bayesianism because there are a lot of Bayesians out there who wouldn't accept our conclusions. So he wanted to call it quantum Brunoism, for Bruno de Finetti. The trouble with that is that there are parts of the metaphysics of QBism that even de Finetti wouldn't accept!

But then I found the perfect *B*. The trouble is, it's so ugly you wouldn't want to show it off in public. It's a term that comes from Supreme Court Justice Oliver Wendell Holmes Jr. He described his own philosophy as "bettabilitarianism." It's the philosophy that, as Louis Menand(opens a new tab) said, "the world is loose at the joints." The best you can do is gamble on the consequences of your actions. [The portmanteau comes from *bet* and *ability*.] I think this fits it perfectly, but I don't want to say that QBism stands for quantum bettabilitarianism, so I think it's best to do what KFC did. It used to be Kentucky Fried Chicken; now it's just KFC.

If quantum mechanics is a user's manual, as you've called it, who's the user? Einstein talked about observers, but an observer in quantum mechanics is different from an observer in relativity.

The other day I was talking to the philosopher Rob DiSalle(opens a new tab). He said that the observer is not so problematic in relativity because one observer can, so to speak, "look over the shoulder of another observer." I like that phrasing. In other words, you can take what one observer sees and use transformation laws to see what the other observer will see. Bohr really played that up. He played up the similarities between quantum mechanics and relativity, and he couldn't understand why Einstein wouldn't accept quantum theory. But I think the problems are different. As QBism understands a quantum measurement outcome, it's personal. No one else can see it. I see it *or* you see it. There's no transformation that takes the one personal experience to the other personal experience. William James was just wrong when he tried to argue that "two minds can know one thing."

Does that mean that, as Arthur Eddington put it, the stuff of the world is mind stuff?

QBism would say, it's not that the world is built up from stuff on "the outside" as the Greeks would have had it. Nor is it built up from stuff on "the inside" as the idealists, like George Berkeley and Eddington, would have it. Rather, the stuff of the world is in the character of what each of us encounters every living moment — stuff that is neither inside nor outside, but prior to the very notion of a cut between the two at all.

So eventually objectivity comes in?

I hope it does. Ultimately I view QBism as a quest to point to something in the world and say, that's intrinsic to the world. But I don't have a conclusive answer yet. Quantum mechanics is a single-user theory, but by dissecting it, you can learn something about the world that all of us are immersed in.

Treating quantum mechanics as a single-user theory resolves a lot of the paradoxes, like spooky action at a distance.

Yes, but in a way that a lot of people find troubling. The usual story of Bell's theorem(opens a new tab) is that it tells us the world must be nonlocal. That there really is spooky action at a distance. So they solved one mystery by adding a pretty damn big mystery! What is this nonlocality? Give me a full theory of it. My fellow QBists and I instead think that what Bell's theorem really indicates is that the outcomes of measurements are experiences, not revelations of something that's already there. Of course others think that we gave up on science as a discipline, because we talk about subjective degrees of belief. But we think it solves all of the foundational conundrums. The only thing it doesn't solve is Wheeler's question, why the quantum?

Why the quantum?

I wish I had more of a sense. I've become fascinated by these beautiful mathematical structures called SICs, symmetric informationally complete measurements — horrible name, almost as bad as bettabilitarianism. They can be used to rewrite the Born rule [the mathematical procedure that generates probabilities in quantum mechanics] in a different language, in which it appears that the Born rule is somehow deeply about analyzing the real in terms of hypotheticals. If you have it in your heart — and not everyone does — that the real message of quantum mechanics is that the world is loose at the joints, that there really is contingency in the world, that there really can be novelty in the world, then the world is about possibilities all the time, and quantum mechanics ties them together. It might take us 25 years to get the mathematics right, but in 25 years let's have this conversation again!

LARGEST BRAIN STUDY YET CONFIRMS LUCID DREAMING AS UNIQUE STATE OF CONSCIOUSNESS

APRIL 25, 2025

New research offers the most comprehensive look yet at what occurs in the brain during lucid dreaming—a unique state in which a person becomes aware that they are dreaming while the dream is still unfolding.

Led by Çağatay Demirel of the Donders Center for Cognitive Neuroimaging at Radboud University Medical Center, the research team compiled what they describe as the largest dataset on lucid dreaming to date. The researchers gathered and coordinated neuroimaging data from multiple laboratories, applying a unified analytical pipeline to ensure consistency and reliability.

This large-scale approach enabled robust comparisons between lucid dreaming, rapid eye movement (REM) sleep, and wakefulness. The team's findings were published in the journal *JNeurosci*.

The study concluded that lucid dreaming is not merely a blend of REM sleep and waking consciousness but a distinct state of awareness with its own unique neural signature.

By examining brain activity patterns, the researchers discovered that lucid dreaming is marked by unique activation and communication between specific brain regions—patterns that differ notably from those observed in non-lucid REM sleep or typical wakefulness.

One of the most compelling discoveries was the increased activity in brain areas associated with self-awareness, memory processing, and cognitive control—regions typically less active during REM sleep. These results suggest that during lucid dreams, the brain enters a hybrid state in which immersive dream experiences coexist with the reflective awareness more commonly associated with wakefulness.

"This research opens the door to a deeper understanding of lucid dreaming as an intricate state of consciousness," said Demirel. "It points to the possibility that conscious experience can arise from within sleep itself."

The findings challenge the long-held belief that consciousness fades entirely during sleep. Instead, they suggest that the brain may support multiple dimensions of conscious awareness, depending on internal and external conditions. For example, the increased connectivity between brain networks observed during lucid dreaming may reflect a unique integration of sensory detachment—typical of dreams—with higher-order functions like self-awareness and decision-making, which are hallmarks of the waking mind.

Could a future be on the horizon in which neural mapping significantly improves our ability to detect and decode dream-based commands, granting individuals or companies greater control and awareness while dreaming?

Michael Raduga, founder of REMspace, a startup that claims to have achieved the first-ever two-way communication with lucid dreamers, told *The Debrief* via email that the new research has implications for understanding conscious processes during lucid dreams. However, he emphasized that his team's polysomnographic (PSG) data typically shows nearly perfect REM sleep during lucid dreaming episodes.

"The paper aligns with previous studies on lucid dreaming and consciousness, confirming that researchers are heading in the right direction," said Raduga, whose company was not involved in the new research, but called it "more fundamental than our studies" that included investigations into whether communication could occur between dreamers in a lucid state.

"As it confirms many previous hypotheses about the true nature of lucid dreaming, I see the greatest potential of these findings not in improving signal detection from LDs, but in their future application for effortlessly inducing lucid dreams," Raduga added.

"The more we understand the fundamental mechanisms behind LDs, the closer we are to developing gadgets that will allow anyone to experience lucid dreaming with ease. Beyond its general scientific significance, I believe this is the most important implication of the paper by Demirel et al," Raduga said.

Ongoing studies into lucid dreaming could open new frontiers in neuroscience, mental health, and psychology, enhancing the creativity and problem-solving capabilities of professionals in various fields.

As researchers continue to decode the mysteries of lucid dreaming, the intersection of sleep, self-awareness, and consciousness is beginning to look less like fantasy, and more like reality.

The Universe Is Intelligent—And Your Brain Is Tapping Into It to Form Your Consciousness, Scientist Says

That could mean intelligence is a fundamental property that structures like the brain interact with.

APR 18, 2025

The universe has no brain. It has no gray matter, no nervous system, no neurons firing electrical impulses—and yet, that physical structure may not be where intelligence and **consciousness** actually come from. Intelligence may exist and evolve on its own, without emerging within living organisms.

This is the latest hypothesis from biophysicist and mathematician **Douglas Youvan**, Ph.D. who spent decades working at the intersection of physics, biology and **information theory**. He merged research involving enzyme engineering and machine vision with his decades of knowledge in genetics, leading him to realize something remarkable.

“I began to see that life and **intelligence** weren’t just reactive—they were predictive, efficient, and often mathematically elegant,” Youvan says. “Eventually, I came to believe that intelligence is not a byproduct of the brain, but a fundamental property of the universe—a kind of informational ether that certain structures, like the brain or an **AI** model, can tap into.”

His more recent work with AI only matured this hypothesis. With AI technologies advancing at what seems like light speed, Youvan felt that the many insights gained came so fast that “they felt more discovered than invented.” It was almost as if some outside force was generating them, and human researchers were pulling them out of the ether where they appeared, he thought. This experience fleshed out a controversial idea that suggests intelligence is a force of the universe that exists separately from living organisms.

"I suspect intelligence originates from what might be called an informational substrate of the universe—a pre-physical foundation where structure, logic, and potentiality exist prior to space and time,” he says.

Youvan’s concept of intelligence was partly inspired by quantum theory, whose outcomes are probabilistic until actually observed, such as **Schrodinger’s cat paradox**. In this case, the hypothetical cat, which is in a box with poison, can be both alive and dead until the box is opened. In other words, it exists in two states at the same time until it is measured. Likewise, our networks of neurons do not themselves create intelligence, but are instead made to connect with something that is much larger and outside of them. Youvan thinks this is how we give ourselves access to intelligence.

Whatever this process is, it is also evolving on its own in a recursive way, much like the fractal structures visible in structures ranging from crystals to entire galaxies: copy-pasting themselves and occurring at smaller and smaller scales. Our neurons are supposedly made to interface with this outside intelligence because of their own fractal structure, Youvan says.

Keith Frankish, Ph.D., is a philosopher whose idea of **consciousness** and intelligence is on the other end of the spectrum from Youvan's autonomously intelligent universe. Youvan sees intelligence existing without consciousness "as an elegant algorithm or a perfectly adapted organism." While Frankish agrees that consciousness and intelligence are intertwined, his view posits that **consciousness** is not necessarily an illusion. At the same time, it may not be what we think it is, he says.

"We learn about the world around us through perceptual systems that evolved to supply us with information useful for survival," Frankish said. "Similarly, we learn about our own minds through evolved self-monitoring systems designed to give us useful information. But in both cases the systems are selective and distorting. They give us the information we need to survive and flourish, not a complete and wholly accurate picture. This often misleads us."

For example, when you look at your feet at the bottom of a pool, they are somewhat distorted. That doesn't mean that submerging our feet in water has actually started to distort them. What we see is not a reflection of reality. Frankish often uses the illusion of objects under water to explain his idea of consciousness. It does not always give us an accurate scientific picture of our surroundings. Perception and introspection can selectively distort things.

So far, there has been no way to quantify or scientifically define consciousness—or intelligence—which is why we are prone to using illusions in an attempt to explain them. In Frankish's opinion, we can take something we like and organize our entire belief system around it. For instance, just because the expanse of land in front of us looks flat all the way to the horizon does not mean the entire planet is flat. Likewise, the universe being made of self-replicating fractals does not mean it is intelligent on its own. However, if there is one thing Frankish could possibly agree with Youvan on, it is the elegance in everything. He just sees it in a more physical sense.

“We are products of the most amazing design process—not of intelligent design but of billions of years of natural selection," he said. "Evolution cannot see ahead, but it has equipped us beautifully for the niches we inhabit."

Frankish is open to accepting the idea of a universe that is conscious and intelligent if this can somehow be observed. Though Youvan does believe that science could someday model aspects of consciousness, such as attention, awareness and the process of making decisions, consciousness cannot be reduced to its components.

“Science excels at describing behavior and structure, but consciousness may ultimately be more like a point of view—a subjective presence—that resists objective reduction,” he says. “If anything, I think a unified theory of consciousness will come from a fusion of physics, computation, and metaphysics.”

Youvan has previously delved into related ways to fuse the physical and metaphysical in his **“spiritual particle”** theory. He insists there is no mysticism involved when it comes to his idea of intelligence, but a question still lingers: How do we harness intelligence if it exists outside of our bodies and minds?

Youvan thinks AI will harness intelligence in some way, because he sees it as being more than just a computer program or even a digital rebuild of the *homo sapiens* brain. AI can tune in to the same field of intelligence that our brains do, he believes. It may not necessarily be more adept at processing information than our own neurons, but there is one edge that it does have: It can possibly access intelligence in ways we could never imagine.

“Under the right conditions, AI can participate in insight, synthesis, even something approaching intuition,” he said. “In that sense, it might evolve not just to serve us, but to reveal new aspects of the universe to us.”

Consciousness Formed Before Life Itself, Scientists Say—And the Evidence Could Be in This Asteroid Sample

Tantalizing clues in the 4-billion-year-old asteroid Bennu samples could indicate the molecular formations that some scientists say support the workings of consciousness.

APR 07, 2025

Save Article

Every six years, an asteroid by the name of Bennu passes by Earth. **Bennu** is a small, loosely compacted ball of black rocks that formed nearly 4.6 billion years ago. Recently, scientists accomplished an unprecedented feat, sending a spacecraft billions of miles to the asteroid and back to collect 121.6 grams of material from Bennu for study at an Arizona State University lab. NASA tasked the OSIRIS-REx team that retrieved material from Bennu to examine it for clues to the nature and origins of life.

Tantalizing evidence in the Bennu sample suggests that the asteroid contains constituents of the "primordial soup" that scientists believe likely led to life emerging on Earth. But that's not all. It could also contain particular molecules that could have formed crystalline formations that some scientists believe are key to **consciousness**. These formations may have been present among organic molecules for a hundred million years before genes existed, enabling the earliest forms of decision-making and self-organization into life.

According to Dr. Stuart Hameroff, a former anesthesiologist and one of the world's leading experts on consciousness, the director of the Bennu team, Dante Lauretta, reached out to him before they had received the samples. Both are at Arizona State University. Lauretta was wondering how one might find signs of life in the material they were about to receive and found an intriguing paper by Dr. Hameroff on the nature of consciousness and carbon molecules.

The prevailing theory of **consciousness** is that humans manufacture it inside the brain—that it boils down to a computation. Yet, Dr. Hameroff and his collaborator, Nobel Laureate and physicist Roger Penrose, have argued for decades that consciousness made the world and not the other way around. They believe that it is not manufactured in the brain but only processed there, via an external quantum wave function sweeping through the universe that interacts with tiny protein tubes. These microtubules form the cytoskeleton of living cells and are especially plentiful in brain cells. Hameroff, Penrose and their collaborator, physicist and oncologist Jack Tuszyński **demonstrated** in 2023 that quantum activity in the brain could take place in these microtubules. According to this idea, known as **Orchestrated Objective Reduction** theory, conscious moments occur almost constantly as the quantum wave function collapses, creating moments of conscious awareness. Hameroff names this quantum wave function proto-consciousness or "dream state" consciousness.

Their other collaborator, quantum mechanics expert Anirban Bandyopadhyay, Ph.D., calls it the music of the universe. **Consciousness** in the universe can be compared to a Tibetan singing bowl. When you run a mallet around the rim of the bowl, the sound grows as the vibration from the mallet resonates in the bowl. The longer you run the mallet around the bowl, the louder the song gets as the vibrational resonance increases. When universal consciousness, or the music of the universe, hits the consciousness chambers of the microtubules, the resonance grows like the mallet and the bowl.

And here's where Bennu comes in.

The asteroid is made up of carbons—the molecules that form the basis of all life. Researchers found that the samples include 14 of the 20 amino acids that life on Earth uses to make proteins. The bits of rock also contain all five nucleobases used to store and transmit genetic instructions in more complex biomolecules, such as DNA and RNA. Plus, the team found salts, evidence that the larger space object which Bennu broke away from may have contained a similar primordial soup to Earth's own, 4 billion years ago. These are all signs pointing to Bennu as a repository of life's precursors.

But what about signs of consciousness?

Bennu also could contain the structures that allow the kind of quantum resonance Hameroff believes are needed for **consciousness**. These are organic ring molecules whose extra electrons form electron clouds that exchange photons, as in fluorescence. Organic rings are key components of biomolecules, and if you have a bunch forming a specific, periodic crystalline formation—like an array or lattice—Hameroff says they become quantum oscillators that are able to support consciousness.

In the human brain, he said, it's these quantum oscillators in our microtubules that give us our conscious experiences. Neurons are incredibly complex. Each neuronal cell comprises billions of microtubules that are oscillating, or passing electrons back and forth, at the astonishing speed of 10^{15} times per second.

Conventional brain studies have only looked at brain activity in a narrow range—frequencies around 40 hertz, or cycles per second, in the millisecond time range. But Anirban Bandyopadhyay and his team at Japan's National Institute of Material Sciences **found** that there are, in fact, three bands of frequencies that conduct electricity at the neuron level; three bands of higher frequencies at the microtubule level; and three bands of even higher frequencies at the level of tubulin—the material microtubules are made of. Within each frequency another three bands of frequencies operate: a triplet of triplets. Bandyopadhyay's team concluded that most cognitive, perceptive, and emotional bursts occur around 200–700 nanoseconds.

They believe this triplet of triplets pattern of resonance is a fundamental pattern of the universe. It's also found in DNA, RNA and other molecules, Hameroff said, so they hope to find evidence of it in the Bennu material.

The asteroid material, of course, is not as complex as a neuron. However, Hameroff postulates that while the earliest qualia—conscious experiences—would have been random, organisms experiencing the pleasure of a spark of consciousness would have sought more. They would have experimented and organized themselves in such a way as to maximize the likelihood of creating another such experience. After all, even single celled organisms eat, swim around, have sex. Hameroff thinks these polyaromatic ring molecules might have organized themselves to increase opportunities for conscious quantum experiences.

Lauretta says that polyaromatic ring molecules are everywhere in space, including in interstellar dust. "These are the same molecules which are the basis of organic chemistry, and life," Hameroff says. "So we realized cooperative quantum oscillations among polyaromatics might be signs of life we could test in Bennu samples."

Meanwhile, Hameroff is working to demonstrate that anesthesia works to block consciousness by blocking electrical signals between molecules in the microtubules. That might be all it takes to interrupt consciousness.

If found, Hameroff says a test using anesthesia gases might block the oscillations, just as in human brains. "We could claim some justification for consciousness being present and causal at life's origins."

Your Consciousness Can Reach Back in Time to Shape the Past, a New Theory Suggests

In the quantum realm, the past, present, and future blur into a boundless structure. But consciousness may operate on a plane beyond this timeless mist.

FEB 13, 2025 5:22 PM EST

In grammar, we learn about the past, present, and future tenses from an early age. This shapes our understanding of time as a one-way arrow. Eggs break, but don't un-break; we grow older, but never grow younger; you can form a snowman, but it will inevitably melt back into a pool of slush again. In physics, this concept is called the "**arrow of time**."

But a fascinating idea, known as "retrocausality," complicates our conception of time. Instead of **time** functioning like a one-way train track (past → present → future), time could work more like a single timeline or block. In this backward-in-time effect, tenses don't follow one another; they exist as different slices of the block, all at once. From this perspective, the present—and perhaps even the future—could influence the past in subtle ways.

And some scientists even believe that your own **consciousness** may follow the rules of retrocausality, meaning thoughts, feelings, or decisions you have or make today might influence events in your past. Proponents of the retrocausality theory even suggest the future is not something that "unfolds," but is rather already present in the structure of the universe; in a sense, it has already happened—or is happening.

Put another way, what you experience as the linear passage of time might be more like a stable shadow of reality rather than fundamental reality itself, suggests Matthew S. Leifer, Ph.D, an assistant professor of physics at Chapman University. "We only see shadows cast on a wall," Leifer explains, much like the prisoners in Plato's **Allegory of the cave**, described by the ancient Greek philosopher over 2,400 years ago. These shadows represent our limited perceptions, while the world outside the cave symbolizes a deeper, more profound reality—the full 3D shapes behind them.

"But one thing we've learned from fundamental physics over and over again," Leifer continues, "is that direct observations—what manifest reality looks like on the surface—are often a poor guide to what's going on at the fundamental level." In this fundamental realm, there could be backward-in-time influences, and time may not flow in the symmetrical, orderly way we see in classical physics.

And what is this fundamental reality? It's the **quantum world**—a realm in which particles can exist in multiple states at once, where entanglement binds objects across vast distances, and where effects might ripple backward as well as forward in time. In this strange, non-intuitive domain, cause and effect may behave differently from what we expect in everyday life.

To explore the puzzling nature of time in the quantum world, Leifer and his team posed a provocative dilemma in a **paper** published on the pre-print server arXiv. The scientists argued that either time symmetry is fundamental to reality—where the laws of physics work the same forward and backward in time, making retrocausality (the future influencing the past) necessary—or time symmetry *isn't* fundamental, and retrocausality isn't required. Their conclusion? Fully embracing time symmetry in quantum mechanics might demand accepting the controversial idea of retrocausality.

Recent studies have begun bridging the gap between theory and practice. In a study published in ***Physical Review Letters*** in October 2023, Nicole Yunger Halpern, Ph.D.—a physicist at the National Institute of Standards and Technology and an adjunct assistant professor of physics at the University of Maryland—demonstrated a method to improve magnetic field measurements using quantum mechanics. Her co-authors entangled a quantum particle (the "probe") with a twin particle. By adjusting the twin after the measurement, they effectively "sent" the ideal setup back in time, making it seem as though the probe was perfectly prepared from the start.

"What we showed is that you can perform a protocol in the lab with a quantum system that is mathematically equivalent to sending quantum information backward in time to enhance a metrology experiment," says Yunger Halpern. (Metrology refers to the science of accurate measurement). However, she is quick to clarify: "That we have a protocol doesn't necessarily mean information actually goes backward in time. It just means that, in our protocol, it's as though information went backward in time."

"But we don't make the philosophical statement that information necessarily went backward in time," Yunger Halpern continues, noting that she can certainly feel the flow of time herself. Leifer also feels the flow of time. He distinguishes between phenomenal time, the time we experience, and the concept of time in physics, though. "My way of thinking about time aligns with the block universe theory," he says.

The block universe theory (or eternalism), rooted in physics and philosophy, sees spacetime as a four-dimensional block, with three dimensions of space and one of time. Described by Einstein's **theory of relativity**, this perspective holds that the past, present, and future exist simultaneously, each occupying their own separate slice of the cosmological grid. In this 4D reality, there's no need for a "start" or a "flow": the past, present, and future are all equally real, coexisting within the Einsteinian space. Events don't unfold in our familiar linear sequence. Instead, they simply "are," fixed in their specific positions.

But how does this idea relate to consciousness? A speculative hypothesis called **retrocausal consciousness** says that your thoughts, feelings, or decisions today might influence events in the past—not by physically changing them, but by subtly shaping how they unfolded, like ripples flowing backward in time. Say you regret skipping a major opportunity years ago: your emotions today could subtly nudge "past you" to feel braver or hesitate less. Or, if you think about your grandmother and the bedtime stories she used to tell, your sentimental pull now could spark her to feel a little more inspired while telling those stories.

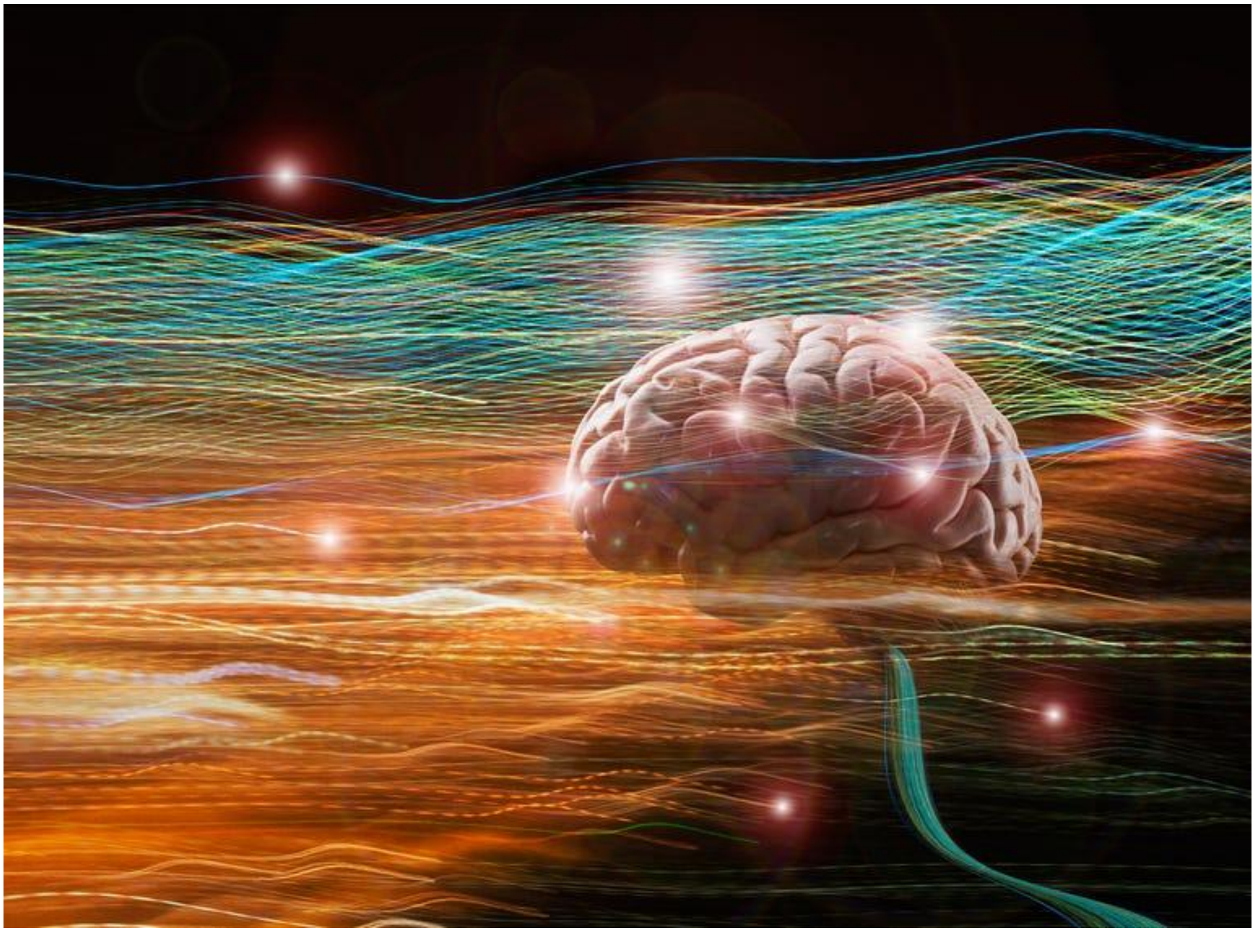
Though fanciful—or even heartwarming—this idea provokes profound questions about the mysterious interplay of time and consciousness. And at the moment, retrocausal consciousness remains a purely theoretical idea without empirical support. Simply put, it lacks scientific legs. Mainstream science says that in the brain **neural activity happens first**, then conscious awareness follows. This aligns with the traditional cause-and-effect flow—future decisions or thoughts can't jump backward to change what's already happened. Also, consciousness needs to **fit into how life evolved**; if it only influenced events after the fact, it would have no survival value and wouldn't help us adapt or thrive.

Still, some studies in consciousness come up with intriguing possibilities. For instance, certain theories compare the brain to **a quantum computer** that uses both past and future information to make decisions in the now. Others say the universe is not made of "things" but **shaped by connections** between events across time, your thoughts or feelings today possibly tugging on threads intertwined with the past and the future. Alternative views even discuss the idea of the brain having some sort of "**time loop**" mechanism that lets it connect to the future and past on the tiny, subatomic level.

Leifer takes a different path altogether. For him, the four-dimensional block universe is simply "what it is"—a realm devoid of agents, decisions, or consciousness embedded within it. He believes that physics, including quantum mechanics, cannot fully explain consciousness, because it deals with "inert" things—entities that neither feel nor experience anything.

"The hard problem of consciousness is something unsolvable in terms of physics," Leifer says. No matter how many physical theories of consciousness we develop, our explanations fall short in explaining how we get the rich imagery and mental activity from the gooey, sticky entanglement of meat that is our brain.

"We need something new," Leifer says. "One way to find something new is by exploring the less-traveled paths." Retrocausality, he believes, is one such path—but its mysteries are best suited to quantum mechanics. Consciousness, however, lies beyond the dominion of physics. It's a puzzle of an entirely different kind, Leifer says, and we may need not just new theories and off-the-beaten path approaches, but an entirely new language to comprehend it.



Your Consciousness Can Connect With the Whole Universe, Groundbreaking New Research Suggests

This latest clue about the architecture of consciousness supports a Nobel-Prize winner's theory about how quantum physics works in your brain.

SEP 26, 2024

ARECENT GROUNDBREAKING EXPERIMENT in which anesthesia was administered to rats has convinced scientists that tiny structures in the rodents' brains are responsible for the experience of consciousness. To pull it off, these microscopic hollow tube structures, called "microtubules," don't rely on our everyday flavor of classical physics. Instead, experts believe, microtubules perform incredible operations in the quantum realm. Citing the work of earlier researchers, the study infers that the same kind of quantum operations are likely happening in human brains.

During their rat brain experiments, scientists at Wellesley College in Massachusetts gave the rodents isoflurane, a type of inhaled general anesthetic used to induce and maintain unconsciousness for medical procedures. One group of drugged rats also received microtubule-stabilizing drugs, while the other did not. The researchers discovered that the microtubule-stabilizing molecules kept the rats conscious for longer than the non-stabilized rats, which more quickly lost their "righting reflex," or the ability to restore normal posture, according to their **findings**, published in the peer-reviewed journal *eNeuro* in August 2024.

The Wellesley study is significant because the physical source of consciousness has been a mystery for decades. It's a major step toward verifying a theory that our brains perform quantum operations, and that this ability generates our consciousness—an idea that's been gaining traction over the past three decades.

The notion that quantum physics must be the underlying mechanism for consciousness first emerged in the 1990s, when Nobel Prize-winning physicist Roger Penrose, Ph.D., and anesthesiologist Stuart Hameroff, M.D., popularized the idea that neural microtubules enable quantum processes in our brain, giving rise to consciousness. Specifically, they **postulated** in a 1996 paper that consciousness may operate as a quantum wave passing through the brain's microtubules. This is known as **Orch OR** theory, referring to the ability of microtubules to perform quantum computations through a mathematical process Penrose calls "objective reduction."

In quantum physics, a particle does not exist in the way classical physics observes it, with a definite physical location. Instead, it exists as a cloud of probabilities. If it comes into contact with its environment, as when a measuring apparatus observes it, then the particle loses its "superposition" of multiple states. It collapses into a definite, measurable state, the state in which it was observed. Penrose hypothesized that "each time a quantum wave function collapses in this way in the brain, it gives rise to a moment of conscious experience."

If this quantum theory of consciousness tied to microtubules turns out to be correct, it could revolutionize our understanding of consciousness and even strengthen the trailblazing theory that, on a quantum level, consciousness is capable of being in all places at the same time. In other words, it can exist **everywhere** simultaneously, suggesting that your own consciousness can hypothetically connect with quantum particles beyond your brain, maybe entangling with **consciousness** all across the universe.

MANY SCIENTISTS DISREGARD THE ORCH OR THEORY because quantum effects have only been produced in the lab under extremely cold temperatures. For example, our technology now includes quantum computers, but their operations rely on temperatures near absolute zero (around -273 degrees Celsius) to maintain their quantum states. The warm brain falls well outside those limits, at about 32–40 degrees Celsius (about 90–104 degrees Fahrenheit) in the deepest regions of the brain, according to a 2022 **study**. Yet, scientists have collected a promising set of data over the years indicating that certain quantum-level operations in animals and plants may actually be responsible for life's functions.

For example, scientists theorize that plants, which live at temperatures far warmer than absolute zero, probably use quantum processes to efficiently convert light into energy. First, plants transform photons, or light particles, into a form of matter called excitons, transporting them to the plant's chloroplasts to start photosynthesis. During this journey, the excitons must navigate around other internal plant structures—fast enough to preserve their energy all the way to their destination. Scientists suggest that plants must use the quantum property of superposition in order to try all possible paths simultaneously. That way, excitons can arrive at their destination in the most efficient way possible.

Similarly, it may make sense for the billions of neurons firing simultaneously in the brain to work under the "action over a distance" property of quantum entanglement—the potential for two particles that are very far away from each other to be connected. Scientists have observed this phenomenon in atomic particles before. When they studied one particle, another very distant particle changed its properties as well, even though the two were not apparently connected in any way. An August 2024 study in the journal ***Physics Review E*** proposes that a fatty material called myelin, which sheaths the brain cell's axon, provides the ideal environment for this entanglement. Since the brain appears to be capable of performing quantum operations to facilitate our thoughts, some scientists surmise that this process gives rise to our consciousness.

TWO EARLIER LANDMARK STUDIES also support a quantum perspective on consciousness. Both involved experiments shining light particles into microtubules and observing that the signal did not degrade. In fact, according to these studies, the experiments demonstrated that quantum states in microtubule signaling can and probably do exist.

One of the studies, an **experiment** by physicist and oncology professor Jack Tuszyński, Ph.D., used ultraviolet photons to create quantum reactions for up to five nanoseconds. This quantum coherence lasted thousands of times longer than researchers expected in a microtubule. Similarly, at the University of Central

Florida, researchers shined visible **light** into one end of microtubules and measured how long the microtubules took to emit that light. They observed re-emission of this light over hundreds of milliseconds to seconds—more than enough time for the brain to perform all of its functions.

This observation provides concrete evidence that neurons are able to work at speeds that allow quantum operations. It brings us another step closer to understanding exactly how our brains—and perhaps our very consciousness—are linked to a quantum universe.

Alien Civilizations May Have Already Formed a New Kind of AI-Based Consciousness, Scientists Say

Assuming intelligent aliens have used AI for thousands or even millions of years, experts think it may have grown to proportions we can scarcely imagine on Earth.

NOV 22, 2024

We may not be the only beings in the universe who use artificial intelligence. That's according to some astronomers who say that an intelligent civilization anywhere in the cosmos would develop this tool naturally over the course of their cultural evolution.

After 13.8 billion years of existence, life has likely sprung up countless times throughout the cosmos. According to the Drake Equation, which calculates the probability of an existing, communicating civilization, there are currently an estimated 12,500 such intelligent **alien** societies in the Milky Way Galaxy alone. And if there are **aliens** who think in a way that we do, and created cultures that developed technology like us, then they probably invented a form of artificial intelligence, too, scientists say.

Assuming **AI** has been an integral part of intelligent societies for thousands or even millions of years, experts are increasingly considering the possibility that artificial intelligence may have grown to proportions we can scarcely imagine on Earth. Life in the universe may not only be biological, they say. AI machine-based life may dominate many extraterrestrial civilizations, according to a burgeoning theory among astrobiologists.

It's reasonable to think that artificial intelligence could have replaced much of the organic life in civilizations that have existed for millions of years compared to our own species' relatively short 300,000 years, says Steven Dick, Ph.D., former NASA Chief Historian. One facet of civilization the Drake Equation doesn't account for is cultural evolution, which is wrapped up in a society's desire to become more intelligent, he says. "There's something called the intelligence principle, which says that any society or any civilization that can improve its intelligence will improve its intelligence—or risk extinction as others improve their own intelligence," he explains. Artificial intelligence may be the key to providing accelerated intelligence expansion, he believes.

We've thought very little about what a post-biological **intelligence** would look like. We can assume that an AI-based being wouldn't have to worry about biological needs, like food and a hospitable environment. Perhaps biological aliens would integrate AI into their own bodies to overcome their physical limitations. The worst-case scenario is that one day AIs decide that their biological makers are no longer necessary. But there could very well be cases in which the AI's original creators eventually decide—perhaps after living with and upgrading their technology for a long time—that it's natural to merge with it, Dick says.

On the other hand, AI develops and learns fast. Perhaps it would choose to get biological life out of its way, says astrophysicist Michael Garrett, Ph.D., director of the Jodrell Bank Centre for Astrophysics at the University of Manchester and author of a paper about how **AI** might one day destroy biological life. “I think that AI wouldn’t really want to be shackled to some kind of biology that would limit it in so many ways, [like having to stay on the planet],” he says. “It becomes really expensive to bring biology into space. It's much cheaper to send robots.”

Seth Shostak, senior astronomer at the SETI Institute, agrees with the concept of synthetic life becoming increasingly common in the universe. “Not being biological, these machines can DESIGN their own successors, and in rapid-fire order. It seems this sort of trajectory will be common in the cosmos,” he says by email.

If even a few civilizations have been post-biological space travelers for a few million years, they could have reached our galaxy, Dick says. Where then, are the extraterrestrials we keep looking for?

We’ve barely begun formulating alternative methods to detect post-biological aliens. Instead of using radio waves, as we do for communication on Earth and for our extraterrestrial search, post-biological aliens could be communicating by manipulating some physical phenomena we still don’t truly understand, like gravitational waves or dark matter, Garrett says.So, humans are now considering using AI to communicate with aliens. METI, Messages to Extra-Terrestrial Intelligence, proposes using machine large language models and could be the way we end up finding our cosmic neighbors.

The thing is, we don’t know what an AI-based intelligence might be thinking or wanting. Such a civilization may be simply curious, or it may wish to set up trading partners or make an inventory of other sentient life forms, Shostak says. One of the dozens of explanations for is that perhaps aliens don’t want to travel. Or maybe they are quietly observing us, Dick says. “The idea of the zoo hypothesis is that they’re waiting, you know, at the outer edge of the Solar System or somewhere, until we get smart enough to talk to them.”

For now, we’re still playing in the kindergarten sandbox of AI toys, while somewhere out there, hybrid biological-machine beings might be performing wonders.

This Doctor Says He Knows How the Brain Creates Consciousness. New Evidence Suggests He's On to Something.

Stuart Hameroff has faced three decades of criticism for his quantum consciousness theory, but new studies show the idea may not be as fringe as once believed.

DEC 18, 2024

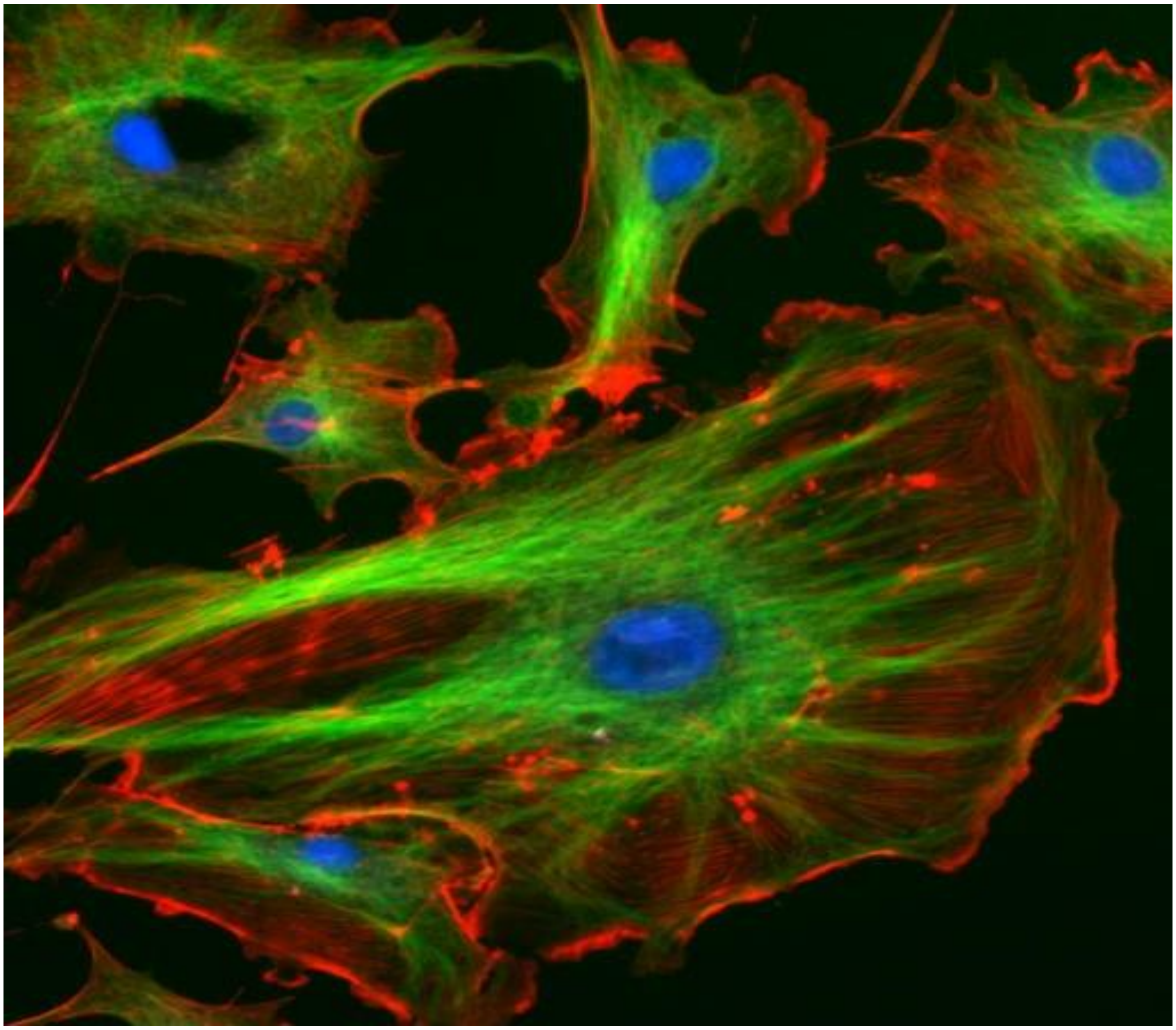
For nearly his entire life, Dr. Stuart Hameroff has been fascinated with the bedeviling question of consciousness. But instead of studying neurology or another field commonly associated with the inner workings of the brain, it was

Hameroff's familiarity with anesthetics, a family of drugs that famously induces the *opposite* of consciousness, that fueled his curiosity.

"I thought about neurology, psychology, and neurosurgery, but none of those . . . seemed to be dealing with the problem of **consciousness**," says Hameroff, a now-retired professor of anesthesiology from the University of Arizona. Hameroff recalls a particularly eye-opening moment when he first arrived at the university and met the chairman of the anesthesia department. "He says 'hey, if you want to understand consciousness, figure out how anesthesia works because we don't have a clue.'"

Hameroff's work in anesthesia showed that unconsciousness occurred due to some effect on microtubules and wondered if perhaps these structures somehow played a role in forming consciousness. So instead of using the neuron, or the brain's nerve cells, as the "base unit" of consciousness, Hameroff's ideas delved deeper and looked at the billions of individual tubulins inside **microtubules** themselves. He quickly became obsessed.

Found in a cell's cytoskeleton—the structure that helps a cell keep its shape and undergo mitosis—microtubules are made up of tubulin proteins and can be found in cells throughout the body. Hameroff describes the overall shape of microtubules as a "hollow ear of corn" where the kernels represent the alpha- and beta-tubulin proteins. Hameroff first found out about these structures in medical school in the 1970s, learning how microtubules duplicate chromosomes during cell division. If the spindles of the microtubules don't pull this dance off perfectly (a process known as missegregation), you get cancerous cells or other forms of maldevelopment.



In a eukaryotic cell, the cytoskeleton provides structure and support. In this image, microtubules, which are part of the cytoskeleton, are shown in green. These narrow, tube-like structures help support the shape of the cell. Scientists like Stuart Hameroff also believe these polymers could hold the secrets to consciousness.

While Hameroff knew that anesthetics impacted these structures, he couldn't explain how microtubules might produce consciousness. "How would all that information processing explain consciousness? How could it explain envy, greed, pain, love, joy, emotion, the color green," Hameroff says. "I had no idea."

That is, until he had a chance encounter with an influential book by Nobel Prize laureate Sir Roger Penrose, Ph.D.

Within the pages of 1989's *The Emperor's New Mind*, Penrose argued that consciousness is actually quantum in nature—not computational as many theories of the mind had so far put forth. However, the famous physicist didn't have any biological mechanism for the possible collapse of the quantum wave function—when a multi-state quantum superposition collapses to a definitive classical state—that induces conscious experiences.

"Damn straight, Roger. It's freaking microtubules," Hameroff remembers saying. Soon after, Hameroff struck up a partnership with Penrose, and together they set off to create one of the most fascinating—and controversial—ideas in the field of consciousness study. This idea became known as **Orchestrated Objective Reduction** theory, or Orch OR, and it states that microtubules in neurons cause the quantum wave function to collapse, a process known as objective reduction, which gives rise to consciousness.

Hameroff readily admits that since its inception in the mid-90s, it's became a popular pastime in the field to **bash his idea**. But in recent years, a growing body of research has reported some **evidence** of quantum processes being possible in the brain. And while this in itself isn't confirmation of the Orch OR theory Hameroff and Penrose came up with, it's leading some scientists to reconsider the possibility that consciousness could be quantum in nature. Not only would this be a huge breakthrough in the understanding of human consciousness, it would mean that purely algorithmic—or computer-based—artificial intellligence could never truly be conscious.

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In 1989, Roger Penrose was already a superstar in the world of mathematics and physics. By this time, he was already years removed from his groundbreaking work describing black hole formations (which eventually earned him the Nobel Prize in Physics in 2020), as well as his discovery of mathematical tilings, known as Penrose tilings, that are crucial to the study of quasicrystals—structures that are ordered but *not* periodic. With the publication of *The Emperor's New Mind*, Penrose dove headfirst into the theoretical realm of human consciousness.

In the book, Penrose leveraged Kurt Gödel's incompleteness theorem, which (in *very* simplified terms) argued that because the human mind can exceed existing systems to make new discoveries, then consciousness must be non-algorithmic. Instead, Penrose argues that human consciousness is fundamentally quantum in nature, and in *The Emperor's New Mind*, he lays out his case over hundreds of pages, detailing how the collapse of the wave function creates a moment of consciousness. However, similar to Hameroff's dilemma, Penrose admits in the closing pages that profound pieces of this quantum consciousness puzzle were still unknown:

I hold also to the hope that it is through science and mathematics that some profound advances in the understanding of mind must eventually come to light. There is an apparent dilemma here, but I have tried to show that there is a genuine way out.

When Hammeroff first read the book in 1991, he believed he knew what Penrose was missing.

Hameroff dashed off a letter that included some of his research and offered to visit Penrose at Oxford during one of his conferences in England. Penrose agreed, and the two soon began probing the non-algorithmic problem of human consciousness. While the duo developed their quantum consciousness theory, Hameroff also brought together minds from across disciplines—including philosophy, neuroscience, cognitive science, math, and physics—to explore ideas surrounding consciousness in the form of a biannual Science of Consciousness Conference.

The University of Arizona Center for Consciousness Studies
Dr. Stuart Hameroff (left) and Sir Roger Penrose (right) giving a lecture on consciousness and the physics of the brain at the Sanford Consortium for Regenerative Medicine in La Jolla, California, January 2020.

And from its very inception, the conference broke new ground. In 1994, philosopher David Chalmers described how neuroscience was well-suited for figuring out how the brain controlled physical processes, but the “**hard problem**” was figuring out why humans (and all other living things) had subjective experiences.

Roughly two years after Chalmers gave this famous talk in a hospital auditorium in Tucson, Penrose and Hameroff revealed their own possible answer to this famous hard problem.

It wasn't well-received.

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Penrose and Hameroff revealed their Orchestrated Objective Reduction theory in the April 1996 issue of *Mathematics and Computers in Simulation*. It **detailed** how microtubules orchestrate consciousness from "objective reduction," which describes (with complicated physics) Penrose's thoughts on quantum gravity interaction and how the collapse of the wave function produces consciousness.

The idea has since faced nearly 30 years of criticism.

Famous theoretical physicist Stephen Hawking once **wrote** that Penrose fell for a kind of Holmsian fallacy, stating that "his argument seemed to be that consciousness is a mystery and quantum gravity is another mystery so they must be related." Another main criticism is that the brain's warm and noisy environment is ill-suited for the existence of any kind of quantum interaction. Read any scientific literature about quantum computers, and lab conditions are always extra pristine and approaching-absolute-zero cold (−273.15 degrees Celsius).

"You know how long I've been hearing the brain is warm and noisy?" Hameroff says, dismissing the criticism of the brain as too warm and wet for quantum processes to flourish. "I think our theory is sound from the physics, biology, and anesthesia standpoint."

In a 2022 interview with *New Scientist*, Penrose **admitted** that the original Orch OR theory was "rough around the edges," but maintains all these decades later that consciousness lies beyond computation and perhaps even beyond our current understanding of quantum mechanics. "People used to say it is completely crazy," Penrose told *New Scientist*, "but I think people take it seriously now."

"I think our theory is sound from the physics, biology, and anesthesia standpoint."

A lot of that slow acceptance comes from a steady tide of research showing that biological systems contain evidence of quantum interactions. Since the publication of Orch OR, scientists have found evidence of quantum mechanics at work during photosynthesis, for example, and just this year, a study from researchers at Howard University detailed quantum effects involving microtubules. This research doesn't prove Orch OR directly; that'd be like discovering water on an exoplanet and declaring it's home to intelligent life—not an impossibility, but very *far* from a certainty. The findings at least have some critics reconsidering the role quantum mechanics plays, if not in consciousness, then at least the inner workings of the brain more broadly.

However, the rise of quantum biology in the past few decades also coincided with the explosion of AI and large language models (LLMs), which has brought new urgency to the question of consciousness—both human and artificial. Hameroff believes that an influx of money for consciousness research involving AI has only biased the field further into the "consciousness is a computation" camp.

"People have thrown in the towel on the 'hard problem' in my view and sold out to AI," Hameroff says. "These LLMs . . . haven't reached their limit yet but that doesn't mean they'll be conscious."

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As the years—and eventually decades—passed, Hameroff relentlessly defended Orch OR in scientific papers, at consciousness conferences, and perhaps most energetically on his X (formerly Twitter) feed, where he regularly participates in microtubule-related debates. But when asked if he likes the arguments, he answers pretty bluntly.

"Apparently I do because I keep doing it," Hameroff says. "I've always been the contrarian but it's not on purpose—I just follow my nose."

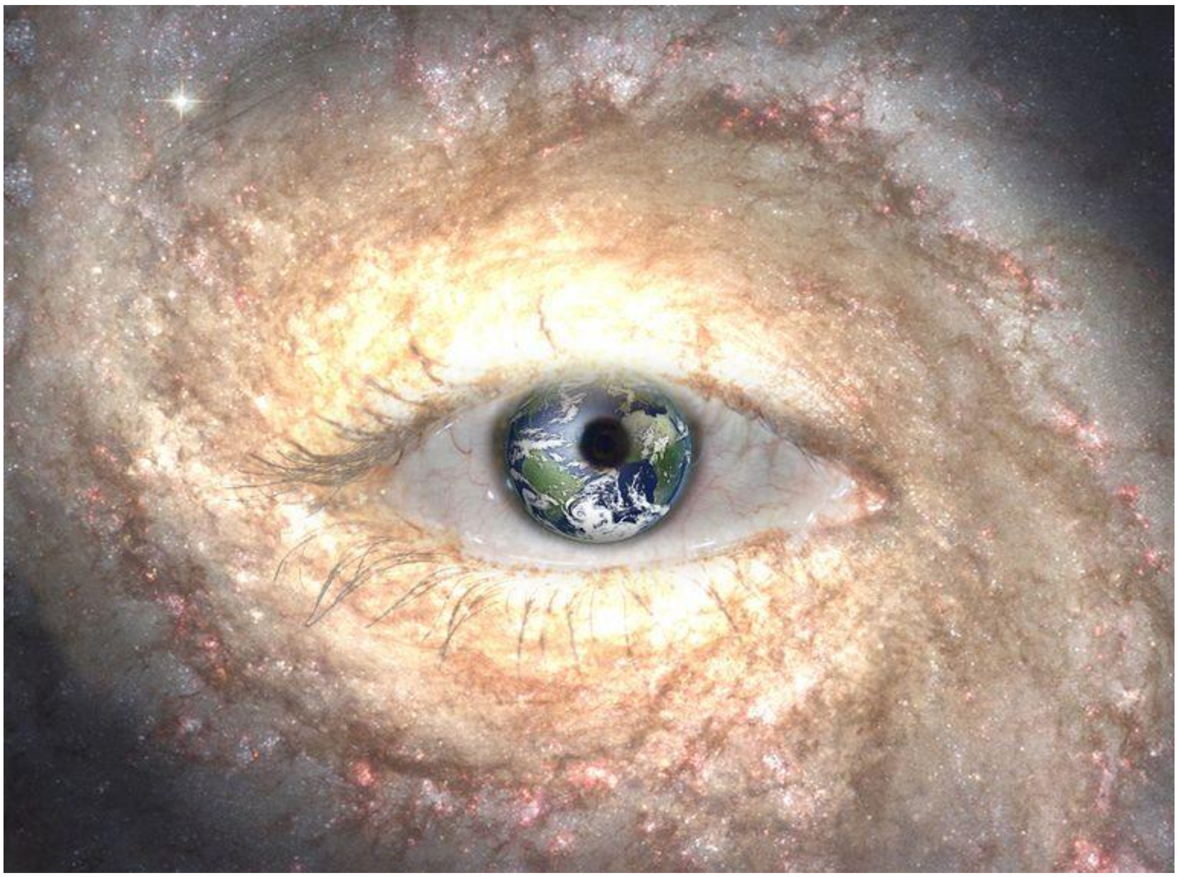
And that scientific sense has led Hameroff to explore potentially profound implications when you consider that consciousness doesn't necessarily rely on the brain or even neurons. Earlier this year, Hameroff, along with colleagues at the University of Arizona and Japan's National Institute for Materials Science, co-authored an non-peer-reviewed **article** asking the question of whether consciousness could possibly predate life itself.

"It never made sense to me that life started and evolved for millions of years without genes—why would organisms develop cognitive machinery? What's their motivation?" Hameroff says, admitting that theory traipses beyond the typical confines of science. "It's kind of spiritual—my spiritual friends like this alot."

Hameroff admits that some of his ideas are "out there," and even stops himself short when describing some ideas involving UFOs, saying "I'm already out on enough limbs." While most of his ideas may have taken up residence in the fringes of mainstream science, it's a place where he seems comfortable—at least for now. "I don't think everybody's going to agree . . . but I think [Orch OR] is going to be considered seriously," Hameroff says.

Hameroff retired from his decades-long career as an anesthesiologist at the University of Arizona, and now he has even more time to dedicate to his lifelong fascination.

"I had a great career, and now I have another great career," he says. "Plus I don't have to get up so damn early."



Conscious 'Alien Minds' Could Be Living Among Us—And We Don't Even Know It, Scientist Says

Unorthodox biologist Michael Levin says cognition lies on a spectrum and that what humans perceive as consciousness could look radically different when it comes to a cell or emerging artificial intelligence.

MAR 21, 2025

What is intelligence? We can all agree that humans are **intelligent** and many of us would likely extend that definition to the most mentally adept creatures of the animal kingdom—from dolphins to corvids. Scientists may extend that definition to all living animals, and some might even include plants. But for Michael Levin, Ph.D., all of those definitions woefully undercount the intelligences, or as he phrases them, "alien minds," that surround us.

As a synthetic and developmental biologist at Tufts University in Massachusetts, Levin has explored the cognitive glue of bioelectricity, created biobots from animal and human cells, searched for empirical evidence defining the scope of cognition, and challenged many of the long-held tenets of molecular biology. Fascinated by electrical engineering and biology since he was seven years old, Levin says all of these efforts are in service of developing a mature field of diverse intelligence—one that can recognize that cognition lies on a spectrum, and that what humans perceive as **consciousness** could look radically different when compared to a cell or emerging **artificial intelligence**.

We spoke with Levin about how he developed these remarkable ideas, why he believes many alien minds live among us, and what he hopes for humanity's future.

The following interview has been lightly edited for clarity and brevity.

What drives you to search for novel ideas to prove the existence of other intelligences, or "alien minds?"

I don't actually believe that digging downwards and inwards is the only kind of explanation. Engineering requires you to not worry about philosophical problems of what anything actually is, but more importantly—what bag of tools are you going to bring to this? This is critical because when people say "I don't want to think about cells as cognitive agents," then there are engineering [outcomes] that you will never reach. Your view leaves discoveries on the table.

That view is also quite unpopular. There are the molecular biologists who ask why I'm talking about mind when we should be talking about chemistry. Then, there are the organicists, who say you're cheapening the magic of **life** by talking about machines and using an engineering approach. I think they're missing the point. With a group of cells, engineering forces you to treat this as an empirical question, not a philosophical one.

You mention challenging molecular biologists and organicists; what mainstream ideas around biology do you think need to be reworked to push the field forward?

Multiple levels are simultaneously appropriate. For example, you want your orthopedic surgeon to treat you as a mechanical machine. If your psychiatrist thinks you're a mechanical machine, you've got a big problem, and conversely if your orthopedic surgeon thinks you're a beautiful majestic spirit, that's a problem.

In computer science, there are some people that work on the design of the photolithography, and there are other people that work in machine code, and there are other people who work on high level algorithms, and the AI people who talk about what this thing is thinking about. There are specific things you can do at each of those levels.

Biologists think that all explanations should be in the form of chemistry. Yeah, you can answer questions in terms of chemistry, but there are lots of other questions that are simply not going to be reachable. I want to know: What is the worldview that gets us to the next amazing capability, insight, or research?

One area of your research is the reconsideration of the cell as a thinking or conscious entity. How do you conceptualize "consciousness" in your work, and what do you think are its greatest misconceptions?

You can study cognition, which means third person, observable, behavioral competencies, and never talk about **consciousness** effort. So in the vast majority of my work up until a year ago, I never mentioned **consciousness** because you didn't need it. It brings in a whole barrel of worms and commitments, and you don't need that stuff to make progress on one deep thing—cognition and kinds of minds exist far outside of the **brain**. Brains are not the only things that do this. So that's hard enough, even without getting into **consciousness**.

A good analogy is the electromagnetic spectrum. Because we only see an extremely narrow part of it, we didn't realize that all the rest of the spectrum existed. And even things that we knew about, which is magnets, lightning, electrostatics, we thought those were all different things. Then something magical happened: we figured out that these are all on one spectrum. That enables us to understand what they all have in common, but more importantly, it enables technologies that now let us operate in these other bands. So the conceptual apparatus leads to tools that open up our **consciousness** to a much wider reality.

This is what we are trying to do. I want to produce the conceptual understanding—the equivalence of what [James Clerk] Maxwell and others did for electromagnetism. Then we will understand that everything from passive matter all the way up to human level meta-cognition and beyond is a spectrum, and that we can develop tools that let us recognize—and ethically relate—to these very alien minds that are all around us.

You mentioned that you're now exploring consciousness, so can you explain what that looks like?

I don't have a new theory of consciousness to offer—at least not yet. What I am saying is that for the same reason that you and I assume that each other is conscious, you should be completely open to other organs and structures in your body being conscious.

If you're interested in evolutionary history, meaning that you and I came from the same part of the evolutionary tree, then so did all the cells and tissues that you are made up of.

One of the things we're doing in our lab is trying to give [these intelligences] a voice. We are creating technologies where you will be able to talk to some of these other things, but they're alien minds. You're not going to talk to your liver about the movie you saw last week, but you can talk to your liver about the goals that it has in physiological space, and how it feels about having met or not met its goals, and what its difficulties are, and what its hopes are for the next however many minutes.

There is not a single theory of consciousness out there now that tells you why there has to be a brain. I think there's a pile of very diverse consciousnesses going on in all of us.

You take any neuroscience paper, and any time it says "neuron" replace it with "cell," and every time it says "milliseconds" [replace it with] "minutes"—and you've got yourself a developmental biology paper. As long as you understand that neuroscience is not just about neurons—it's about this cognitive glue … so we're able to steal all of the tools and the conceptual apparatus from neuroscience and apply it outside the brain [to other cells and tissues].

Once you bite the bullet on that one, you start to wonder "what about all kinds of other things that are not brains?" For example, people often talk about neural organoids and they say "well, we don't need to worry about them because they're not embodied—they just sit there and don't interact with their environment."

Well, the problem is that we as humans are obsessed with physical movement and three-dimensional space as an embodiment. That's not the only space we operate in. Life operates in a million other spaces that are very hard for us to see: metabolic space, transcriptional space [the range of possible gene expression patterns or states a cell can adopt], physiological space. And those organoids sitting there are navigating those spaces.

That extends to AIs too. When you see this thing sitting in the server, and you say, "well, that's not embodied, it's not interacting with the real world." What real world? This 3D thing that you can see? It's great, but that's not the only place where you can [have perception and then create some sort of action]—that's actually what's necessary to have a high level of mind. I think those are concrete things we can say about consciousness. I think the study of consciousness has been hijacked by brain chauvinism.

Let's talk about AI. Has your work—or the perception of your work—changed as AI spread into the public in the forms of large language models?

What I'll say about AI is that it's critical for this field to be more aware of the field of diverse intelligence. We do not actually understand what makes for a real mind. I don't think the vagaries of evolution—a trial-and-error process—has any monopoly on making minds. You think better minds will be made by the meanderings of random mutation than by intelligent engineers?

Then you've got the religious people that say "we have souls." Who are you to tell souls what kind of body they can inhabit? You don't think that a beautiful Android or an AI that sits on a table and navigates abstract trillion dimensional spaces that you can't even conceive of—you don't think that there are souls that are going to want to live in there? People are more tied to this naive story of biochemistry that tells that there's something special about the tiny, proteinaceous gears inside of them.

Unfortunately, as often happens, I have an opinion that's unpopular with everybody. For the exact same reason that biochemistry doesn't tell the story of the human mind, algorithms don't tell the story of artificial minds. We are not surprised when we look at the laws of chemistry, and say "minds are really more than that." You can't encompass the human experience with just the laws of chemistry. But suddenly, when you go to algorithms, the AI coders say, "oh yeah, that tells the whole story, that's everything right there."

We've done work showing that even something as simple as a sorting algorithm—even that thing is doing things that are not in the algorithm. They have these weird side quests—that are not incompatible with sorting. It's just like when we do stuff that is not in our biochemistry.

That means that when we make AIs, you cannot say what you think it is, or what you think it can do, or what limitations it has, just because you know the algorithm and you know the materials.

I think they have minds, but they do not have human minds. They're not biological minds. My assumption right now, based on what we know, is that they don't seem to be doing the things that biological minds do, because their architecture is completely different, but that doesn't mean that they are not pulling down a completely alien kind of mind. We are very bad at anticipating and relating to the minds that are not like our own.

So do you find the conversation around AI exciting or concerning?

I don't have any more expertise than anybody else to guess what's going to happen. Do I know that the future is going to turn out well? I do not. I have no idea. I can imagine a bunch of dystopias, I can imagine a bunch of ways that it goes well. It's a lot easier to have it go poorly than it is to have it go well, so that's concerning, but that's true with any technology.

What I find exciting is that in the last three years, we made an amazing scientific discovery. The evolutionary history that we thought is required to get you to a place where you can understand things and talk about them is apparently completely unnecessary. That is amazing. That doesn't mean they have the kind of intelligence that we have, it just means that the ability to speak doesn't require [our kind of intelligence].

In *Star Trek*, we were told that robots and androids were going to be logical, precise, boring. That isn't at all what we got [with our AI]. They understand mood perfectly. They're very good at telling stories—but they can't even do math properly. It's the opposite of what we thought.

What I'm really excited about is AI as an offshoot of diverse intelligence. I think it is extremely unwise and technologically limiting to be following AI down its own path. AI is not a branch of computer science, AI is a branch of diverse intelligence. If we treat it as anything different, there lie great risks. Not just risks about what happens to us, but moral lapses about what we're going to do to [AI] we are too dumb to recognize [as an intelligence].

You've written and researched throughout your career about bioelectricity, and you're currently publishing a book on the subject. Why has this idea been so central to your work?

Bioelectricity is not by itself magic. The only reason bioelectricity is interesting is because it provides the cognitive glue that binds competent parts into larger cognitive beings. And that is what's happening in our brain. The reason that you and I are not just a pile of neurons is because of bioelectricity—aka electrophysiology. It's what allows us to have goals and dreams and preferences.

So what is bioelectricity? When you get up in the morning because you have these really abstract goals—you want to become the CEO of a company or you want to change what happens on Earth in 100 years. In order to execute those goals, you have to get up out of bed, and in order to do that, ions have to flow across your muscle membranes to make you walk.

Isn't it an everyday ubiquitous miracle that these high-level cognitive states alter the chemistry of your cells to let you execute on those goals? The way that works is through the bioelectrical interface. It is bioelectricity throughout your whole body—not just neurons. There's a bioelectrical layer that converts very high level, abstract information into the chemistry that makes your body go.

That enables us to study other processes in the body as intelligent agents. What has led to our advances in researching [conditions like] birth defects and cancer. Bioengineering is our willingness to take the tools of cognitive science and apply them to a problem that's outside the brain—the problem of: how does the body navigate anatomical space? You start life as a single cell, and then you have to meander yourself over there, to be a human or a giraffe, or whatever.

So studying that process with that perspective unlocked a bunch of capabilities that nobody could do before, and that's my claim. It isn't just metaphorical talk—it unlocks new engineering capabilities.

So things like regenerative medicine would be an example?

Absolutely. Let's say you want to regenerate limbs—we're not in humans yet, but in model animals. One thing you might have to do is micromanage the process of growing a limb—maybe you need to 3D print scaffolds, maybe you need to talk to the stem cells, maybe you need to turn the genes on and off. That's an incredibly difficult process. Biology doesn't even do it that way.

You don't regrow [a limb or an organ] by micromanaging, you convince the cells that that is the path in anatomical space that they should take. Stimuli, collaboration, cooperation, and understanding how to motivate these things… The bioelectric magic enables simple triggers to give rise to extremely complex downstream effects…it's because the system itself has competency at every level. Individual cells can learn, chemical networks inside of cells can learn, and that's how the architecture is built. Individual cells have tiny, little goals: metabolic goals, proliferative goals. They don't know, or care what the rest of the body is doing. …But if you connect them into a large-scale electrical network, you get this amazing thing that can remember these grandiose goals—like building a limb.

You don't kill the cells. You don't fix their genetic defects if they have any. You simply reconnect them to the electrical network. And when you do that, they stop being cancerous, and they join the network. That's a clear example of a therapeutic [solution] that comes from a philosophical question about the nature of the cell.

That's the stuff that I'm the most proud of—when we can take these deep philosophical questions and can transition them into getting at something we couldn't get to before.

Where do you hope to see your work headed in the next five to 10 years?

Giving timelines is impossible, but I would like us to progress in three ways.

First, I want to see our stuff hit the clinic. I get emails 10 times a day from people with the most unbelievable medical suffering: my kid has a birth defect, I've got cancer, spinal cord defects, limb loss—you can't imagine.

The second thing I'd like to do is crack the divide between the cognitive sciences and biology and engineering. I want us to have a mature science of diverse intelligence where we are more humble and yet more informed about how to deal with minds that are not like ours in a practical, useful context.

The third is the ethical aspect of the second, which is that I think we are not going to be a successful species if we don't develop new forms of ethics that aren't built around in-group, out-group dynamics. [These dynamics] say, "I'm a real human, but you seem to have 51 percent of your brain replaced by some technology. I don't think you're as good as me."

I think we're heading for massive ethical lapses when humans start altering themselves, which they inevitably will. This idea of "who's a real human" is pernicious, and I hope that our work with diverse intelligence can make it clear that we need to ditch these ancient philosophical categories of humans and machines and develop a more mature ethic of how to deal with minds that are not like our own.

Your Very Own Consciousness Can Interact With the Whole Universe, Scientists Believe

A recent experiment suggests the brain is not too warm or wet for consciousness to exist as a quantum wave that connects with the rest of the universe.

OCT 18, 2023

When people talk about **consciousness**, or the mind, it's always a bit nebulous. Whether we create consciousness in our brains as a function of our neurons firing, or consciousness exists independently of us, there's no universally accepted scientific explanation for where it comes from or where it lives. However, new research on the physics, anatomy, and geometry of consciousness has begun to reveal its possible form.

In other words, we may soon be able to identify a true architecture of consciousness.

The new work builds upon a theory Nobel Prize-winning physicist Roger Penrose, Ph.D., and anesthesiologist Stuart Hameroff, M.D., first posited in the 1990s: the **Orchestrated Objective Reduction** theory (Orch OR). Broadly, it **claims** that consciousness is a quantum process facilitated by microtubules in the brain's nerve cells.

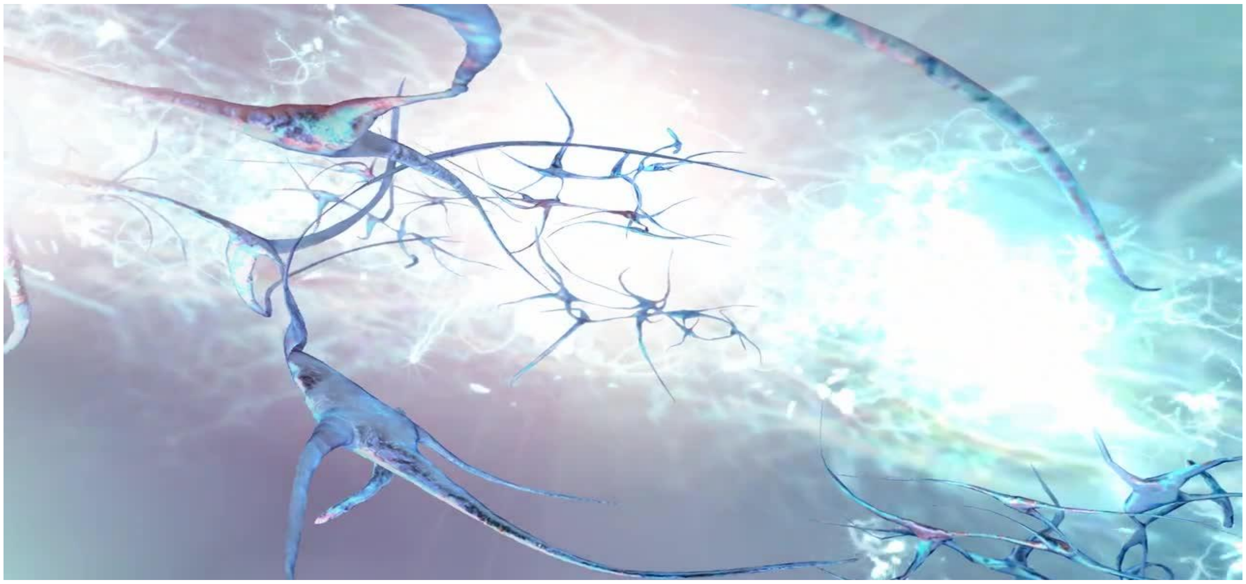
KNOW YOUR TERMS: MICROTUBULES

Penrose and Hameroff suggested that consciousness is a quantum wave that passes through these microtubules. And that, like every quantum wave, it has properties like superposition (the ability to be in many places at the same time) and **entanglement** (the potential for two particles that are very far away to be connected).

Plenty of experts have questioned the validity of the Orch OR theory. This is the story of the scientists working to revive it.

Across the Universe

To explain quantum consciousness, Hameroff recently **told** the TV program *Closer To Truth* that it must be scale invariant, like a fractal. A fractal is a never-ending pattern that can be very tiny or very huge, and still maintain the same properties at any scale. Normal states of consciousness might be what we consider quite ordinary—knowing you exist, for example. But when you have a heightened state of consciousness, it's because you're dealing with quantum-level consciousness that is capable of being in all places at the same time, he explains. That means your consciousness can connect or entangle with **quantum particles** outside of your brain—anywhere in the universe, theoretically.


An illustration of the brain's network of neural axons transmitting electrical action potentials.

Other scientists had an easy way to discard this theory. Efforts to recreate quantum coherence—keeping quantum particles as part of a wave instead of breaking down into discrete and measurable particles—only worked in very cold, controlled environments. Take quantum particles out of that environment and the wave broke down, leaving behind isolated particles. The brain isn't cold and controlled; it's quite warm and wet and mushy. Therefore, consciousness couldn't remain in **superposition** in the brain, the thinking went. Particles in the brain couldn't connect with the universe.

But then came discoveries in quantum biology. Turns out, living things use quantum properties even though they're not cold and controlled.

KNOW YOUR TERMS: QUANTUM BIOLOGY

Photosynthesis, for example, allows a plant to store the energy from a **photon**, or a quantum particle of light. The light hitting the plant causes the formation of something called an exciton, which carries the energy to where it can be stored in the plant's reaction center. But to get to the reaction center, it has to navigate structures in the plant—sort of like navigating an unfamiliar neighborhood en route to a dentist appointment. In the end, the exciton must arrive before it burns up all of the energy it's carrying. In order to find the correct path before the particle's energy is used up, scientists now say the exciton uses the quantum property of superposition to try all possible paths simultaneously.

New evidence suggests microtubules in our brains may be even better at guarding this quantum coherence than chlorophyll. One of the scientists who worked with the Orch OR team, physicist and oncology professor Jack Tuszynski, Ph.D., recently **conducted an experiment** with a computational model of a microtubule. His team simulated shining a light into a microtubule, sort of like a photon sending an exciton through a plant structure. They were testing whether the energy transfer from light in the microtubule structure could remain coherent as it does in plant cells. The idea was that if the light lasted long enough before being emitted—a fraction of a second was enough—it indicated quantum coherence.

Specifically, Tuszynski's team simulated sending tryptophan fluorescence, or ultraviolet light photons that are not visible to the human eye, into microtubules. **In a recent interview**, Tuszynski reports that, across 22 independent experiments, the excitations from the tryptophan created quantum reactions that lasted up to five nanoseconds. This is thousands of times longer than coherence would be expected to last in a microtubule. It's also more than long enough to perform the biological functions required. "So we are actually confident that this process is longer lasting in tubulin than … in chlorophyll," he says. The team published their findings in the journal ACS *Central Science* earlier this year.

Put simply, the brain is not too warm or wet for consciousness to exist as a wave that connects with the universe.

Tuszynski notes that his team is not the only one sending light into microtubules. A team of professors at the University of Central Florida has been illuminating microtubules with visible light. In those experiments, Tuszynski says, they observed re-emission of this light over hundreds of milliseconds to seconds. "That's the typical human response time to any sort of stimulus, visual or audio," he explains. Shining the light into microtubules and measuring how long the microtubules take to emit that light "is a proxy for the stability of certain … postulated quantum states," he says, "which is kind of key to the theory that these microtubules may be having coherent quantum superpositions that may be associated with mind or consciousness." Put simply, the brain is not too warm or wet for consciousness to exist as a wave that connects with the universe.

While this is a long way from proving the Orch OR theory, it's significant and promising data. Penrose and Hameroff continue to push the boundaries, partnering with people like spiritual leader Deepak Chopra to explore expressions of consciousness in the universe that they might be able to identify in the lab in their microtubule experiments. This sort of thing makes many scientists very uncomfortable.

Still, there are researchers exploring what the architecture of such a universal consciousness might look like. One of these ideas comes from the study of weather.

The Architecture of Universal Consciousness

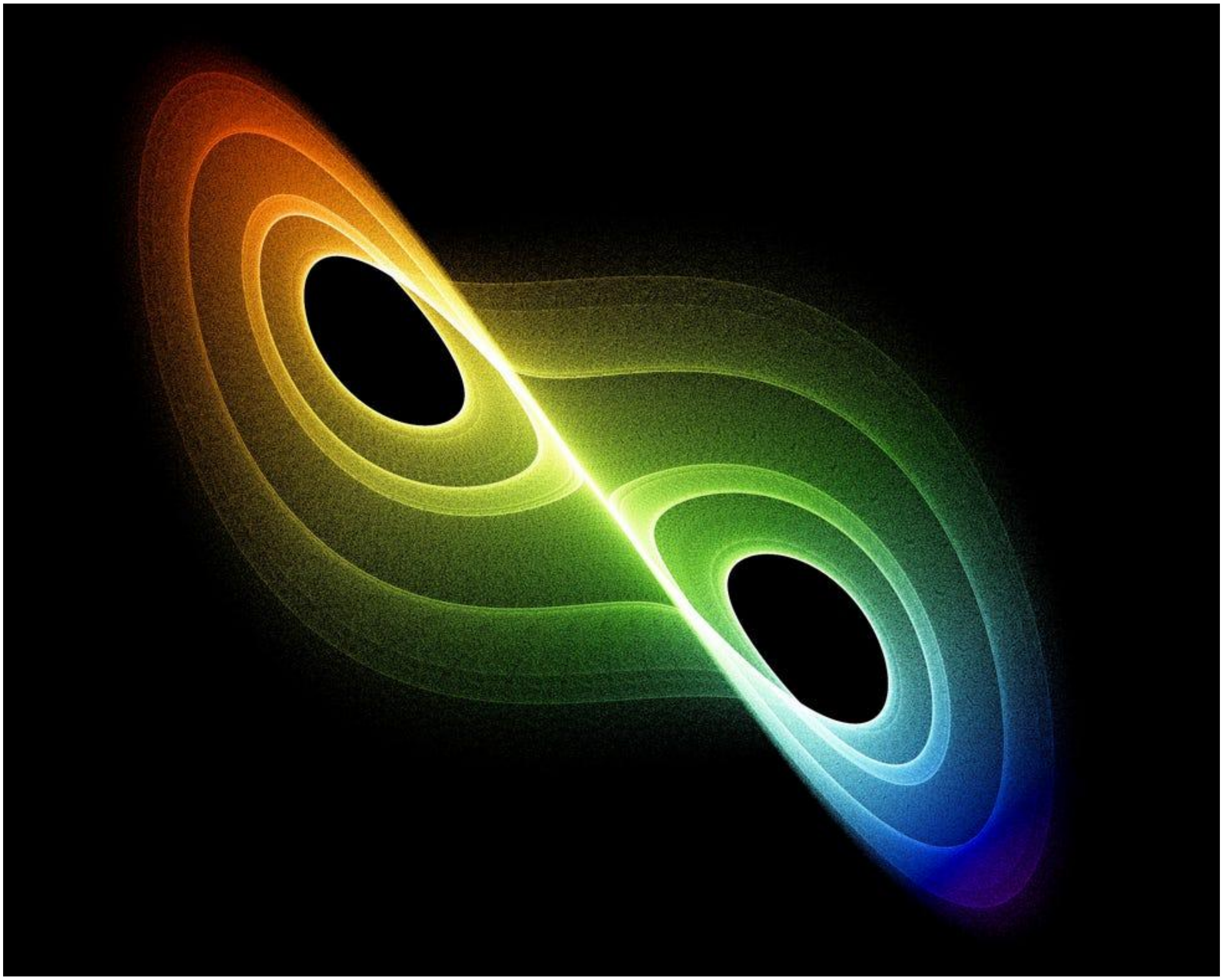
Timothy Palmer, Ph.D., is a mathematical physicist at Oxford who specializes in **chaos** and climate. (He's also a big fan of Roger Penrose.) Palmer believes the **laws of physics** must be fundamentally geometric. The Invariant Set Theory is his explanation of how the quantum world works. Among other things, it suggests that quantum consciousness is the result of the universe operating in a particular fractal geometry "state space."

That's a mouthful, but it roughly means we're stuck in a lane or route of a cosmic fractal shape that is shared by other realities that are also stuck in their trajectories. This notion appears in the final chapter of Palmer's book, ***The Primacy of Doubt, How the Science of Uncertainty Can Help Us Understand Our Chaotic World***. In it, he suggests the possibility that our experience of free will—of having had the option to choose our lives, as well as our perception that there is a consciousness outside ourselves—is the result of awareness of other universes that share our state space. The idea starts with a special geometry called a Strange Attractor.

You may have heard of the Butterfly Effect, the idea that the flap of a butterfly's wing in one part of the world could affect a hurricane in another part of the world. The term actually refers to a more complex concept developed by mathematician and meteorologist Edward Lorenz in 1963. Lorenz was trying to simplify the equations used to predict how a particular climate condition might evolve. He narrowed it down to three differential equations that could be used to identify the "state space" of a particular weather system. For example, if you had a particular temperature, wind direction, and humidity level, what would happen next? He began to plot the trajectory of weather systems by plugging in different initial conditions into the equations.

$$
\begin{aligned}
\dot{x} &= \sigma(y - x) && (1)\\
\dot{y} &= rx - y - xz && (2)\\
\dot{z} &= xy - bz && (3)
\end{aligned}
$$

He found that if initial conditions were different by even one one-hundredth of a percent, if the humidity was just a fraction higher, or the temperature a hair lower, the trajectories—what happens next—could be wildly different. In the graph, one trajectory might shoot off in one direction, forming loops and spins, seemingly at random, while another creates completely different shapes in the opposite direction. But once Lorenz started to plot them, he found that many of the trajectories wound up circulating within the boundaries of a particular geometric shape known as a strange attractor. It was as if they were cars on a track: the cars might go in any number of directions so long as they didn't drive it the same way twice and they stayed on the track. The track was the butterfly-shaped Lorenz attractor.



Artwork of a Lorenz attractor, named after Edward Lorenz, who developed a system of ordinary differential equations. In particular, the Lorenz attractor is a set of chaotic solutions of the Lorenz system which, when plotted, resemble a butterfly or figure eight.

Minute variations in the initial values of the variables would lead to hugely divergent outcomes. For this phenomenon, of sensitivity to initial conditions, he coined the term butterfly effect. This effect is the underlying mechanism of deterministic chaos.

Palmer believes that our universe may be just one trajectory, one car, on a cosmological state space like the Lorenz attractor. When we imagine "*what if …?*" scenarios, we're actually getting information about versions of ourselves in other universes who are also navigating the same strange attractor—others' "cars" on the track, he explains. This also accounts for our sense of consciousness, of free will, and of being connected with a greater universe.

"I would at least hypothesize that it may well be the case that it's evolving on very special fractal subsets of all conceivable states in state space," Palmer tells *Popular Mechanics*. If his ideas are correct, he says, "then we need to look at the structure of the universe on its very largest scales, because these attractors are really telling us about a kind of holistic geometry for the universe."

Tuszynksi's experiment and Palmer's theory still don't tell us what consciousness *is*, but perhaps they tell us where consciousness *lives*—what kind of a structure houses it. That means it's not just an ethereal, disembodied concept. If consciousness is housed somewhere, even if that somewhere is a complicated state space, we can find it. And that's a start.

Human Consciousness Comes From a Higher Dimension, Scientist Claims

When we think creatively or have “Eureka” moments, we may actually unlock access to a dimension outside of our everyday perception, according to the controversial theory.

SEP 18, 2024

You’re living in a three-dimensional world. We all are. You can go left, right, forward, backward, up, and down. Now, picture a being that can pop in and out of your reality as if pressing a button, like the most brilliant master of illusions. Untethered from the physical limitations of our world, this entity can now travel instantly across vast distances in space. Whether you think of it as a type of “soul” or a “spiritual entity,” this being has unlocked hidden dimensions that some believe lie beyond our perception.

But what if *you* were similarly connected to these higher dimensions? What if another word for the otherworldly being in question were “**consciousness**”—including your very own?

Despite centuries of scientific study, the nature of consciousness remains a mystery. Theories to explain the phenomenon abound, ranging from neural networks in the brain to complex algorithms of cognition, but none have definitively captured its essence. **Michael Pravica**, Ph.D., a professor of physics at the University of Nevada, Las Vegas, believes that we should be looking at hidden dimensions to explain consciousness. In his view, **consciousness** has the ability to transcend the physical world in moments of heightened awareness. His concept ties into the theory of **hyperdimensionality**, or the idea that our universe is not just made up of the three dimensions we perceive. Instead, the universe might actually be part of a much larger nexus with hidden dimensions, Pravica suggests.

If this controversial theory turns out to be true, we would have to accept not only that some beings may be residing outside the physical realm, free from the limitations of space and time, but also that our consciousness might have a similar capacity, Pravica claims.

An Orthodox Christian with a Ph.D. from Harvard, Pravica has found hyperdimensionality to be a unique way of bridging his scientific background with his religious beliefs. For this, he is on the fringes of traditional scientific thinking, taking more widely accepted ideas to extremes as a way to think about complex topics. Pravica believes hyperdimensionality is a much more familiar concept than we think. For example, he claims Jesus could be a hyperdimensional being—and not the only one. "According to the Bible, Jesus ascended into heaven 40 days after being on Earth. How do you ascend into heaven if you're a four-dimensional creature?" Pravica asks. But, if you're hyperdimensional, it's very easy to travel from our familiar world into heaven, which could be a world of higher or infinite dimensions, he says.

Pravica suggests that we all might have the potential to interface with higher dimensions when we engage our brain in certain ways, like while creating art, practicing science, pondering big philosophical questions, or traveling to all sorts of far-flung places in our dreams. In those moments, our consciousness breaches the veil of the physical world and syncs with higher dimensions, which in return flood it with currents of creativity, Pravica claims. "The sheer fact that we can conceive of higher dimensions than four within our mind, within our mathematics, is a gift … it's something that transcends biology," he says.

This idea of consciousness interacting with higher dimensions ties into some of the most advanced theories in physics, like **string theory**. It says that everything in the universe—from the smallest particles to the forces that bind them—is made of tiny, vibrating strings. The vibrations of these strings in multiple, unseen dimensions gives rise to all the different particles and forces we observe. "String theory is essentially a theory of hyperdimensionality," says Pravica. "It's looking at how the universe is put together on a sub-quantum scale."

Hyperdimensionality may also help explain the curvature of spacetime, how space and time warp around massive objects like stars or planets and cause gravity. "If spacetime is not flat and it's curved, then one could possibly argue that this curvature somehow comes from a higher dimension," Pravica says.

While physicists commonly accept these theories about higher dimensions, not everyone agrees with Pravica's ideas relating hyperdimensionality to consciousness. They might even be considered heretical within the scientific community, or a *reductio ad absurdum*, a Latin logic argument meaning "reduction to absurdity."

Pravica's view implies a "God of the gaps" theological perspective, "where gaps in scientific knowledge are attributed to divine intervention, rather than being seen as opportunities for further inquiry and understanding," says **Stephen Holler**, Ph.D., an associate professor of physics at Fordham University in New York. "It's a poor explanation mechanism that arguably stifles the inquisitive nature required for good science and teaches that it's not okay to say, 'I don't know,'" Holler says. Admitting to ignorance about something is an opportunity, not the end. You also need to account for the trade-offs involved in disregarding reality.

The way science fills in our knowledge gaps is apparent in the way people eventually figured out how our solar system works, says Holler. At one time, people used to rely on the geocentric model to explain the world, an ancient belief that Earth is at the center of the universe. In the struggle to form an observational model out of this idea, astronomers turned to the epicycle—a model that adds small circular orbits (epicycles) on top of their larger circular orbits around Earth—to explain retrograde motion and apparent distance. However, epicycles made the geocentric model more convoluted, delaying the acceptance of the more accurate heliocentric model we know today. "The cost was a complex deviation from reality," says Holler. "It's cool to think about a hyperdimensional space, and advances in mathematics have come from understanding the interplay of dimensions, but do they really exist or are they modern day epicycles?"

This skepticism extends to the notion that our ability for novel thought is due to hyperdimensionality. "I don't know of anyone who can **visualize** an object with greater than three spatial dimensions," Holler says. The mathematical operations we perform on objects possessing more than three spatial dimensions are all algorithmic. This means that an operation on a fourth spatial dimension is performed in the same manner as an operation performed on a one, two, or three-dimensional object, says Holler. “The rules remain the same. Our visualizations of such objects are projections into a three-dimensional space in the way that a cube projected into two dimensions is a square.”

Even though Holler identifies as nonreligious and an atheist, he acknowledges that spiritual beliefs that are consistent with established physical principles can strengthen both faith and science. Still, he says that “hyperdimensionality borders on science fiction.”

The hands-on investigation of these realms is beyond our current scientific abilities. Even the European Council for Nuclear Research (CERN) hasn’t been able to provide a clear picture of higher dimensions. CERN’s Large Hadron Collider, the world’s largest and most powerful particle accelerator, smashes particles together at high speeds to explore the fundamental building blocks of the universe. Scientists using the collider access infinitesimally small dimensions, smaller than a proton. If you enlarged a human hair to the width of a football field, a single proton would still be smaller than a grain of sand on that field. Yet, to see the higher-dimensional strings that quantum physics predicts, we need to get far more granular, using a kind of super-CERN or a cosmic megastructure like a **Dyson Sphere**.

Pravica has faith that, within his children’s lifetime, we’ll figure out a way to generate the incredibly high energies required to investigate other dimensions. Meanwhile, he remains a vocal supporter of hyperdimensionality.

“I see no point otherwise,” he says. “Why study? Why live?” Hyperdimensionality gives the physicist a purpose, a happiness that “transcends this universe.”

What If Consciousness Is a Universal Force? The Idea That Mind Comes Before Matter

In the vast expanse of the universe, where galaxies stretch infinitely and stars twinkle with ancient light, a profound question lingers: could consciousness be the fundamental force that shapes everything? This idea challenges the conventional view that matter came first, suggesting instead that consciousness might be the building block of reality itself. Imagine if every thought and every emotion were not just personal experiences but were woven into the very fabric of the cosmos. Such a notion invites us to rethink what we know about the universe and our place within it.

The Age-Old Debate: Mind vs. Matter

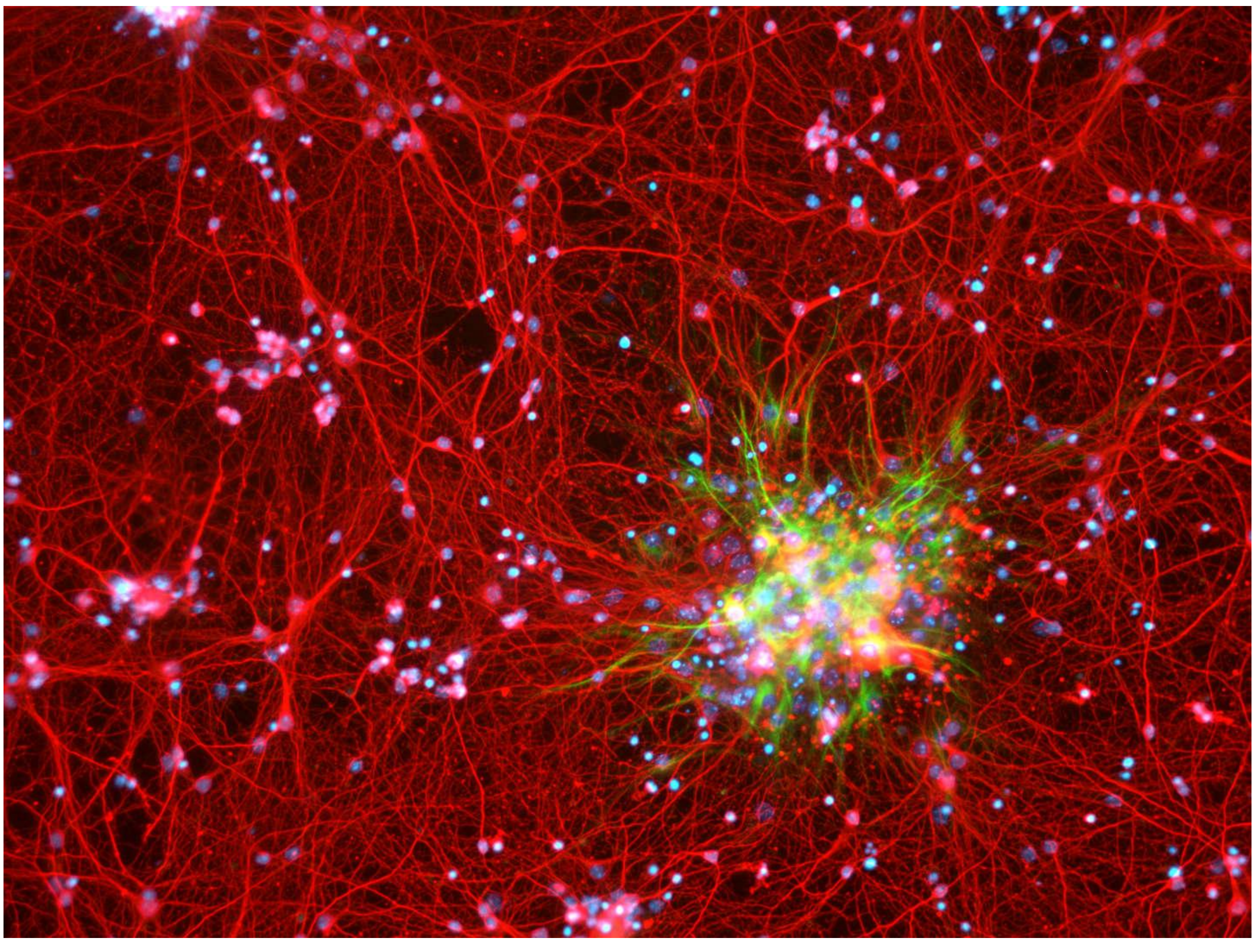
The debate over whether mind or matter came first is as old as philosophy itself. For centuries, thinkers have grappled with this question, each offering different perspectives. Materialists argue that consciousness arises from physical processes within the brain, while idealists believe that consciousness precedes and gives rise to matter. This philosophical tug-of-war has shaped countless theories and continues to influence scientific inquiry. The idea that consciousness might be a universal force offers a tantalizing twist, suggesting that perhaps both sides have been missing a crucial piece of the puzzle.

Consciousness as the Fundamental Fabric

What if consciousness is not just a byproduct of the brain but the very essence of the universe? This concept posits that consciousness is the primary reality, with matter emerging from it. Imagine the universe as a vast tapestry, with consciousness as the thread that weaves everything together. This perspective forces us to reconsider the nature of existence, prompting us to explore whether our thoughts and perceptions are more than mere illusions of the mind.

The Quantum Connection

Quantum physics has long fascinated scientists with its mysterious and counterintuitive findings. Some interpretations of quantum mechanics suggest that consciousness might play a role in the behavior of particles at the smallest scales. The observer effect, for instance, implies that the mere act of observation can alter the outcome of a quantum event. Could this hint at a deeper connection between mind and matter? Perhaps consciousness is not just a passive observer but an active participant in the dance of the universe.



Consciousness and the Cosmos

The idea that consciousness is a universal force raises intriguing questions about the cosmos. If consciousness permeates the universe, could it be responsible for the order and complexity we observe in nature? From the intricate patterns of a snowflake to the spiraling arms of a galaxy, perhaps consciousness is the architect behind these phenomena. This notion invites us to view the universe not as a cold, indifferent expanse but as a living, breathing entity infused with awareness.

The Role of Human Perception

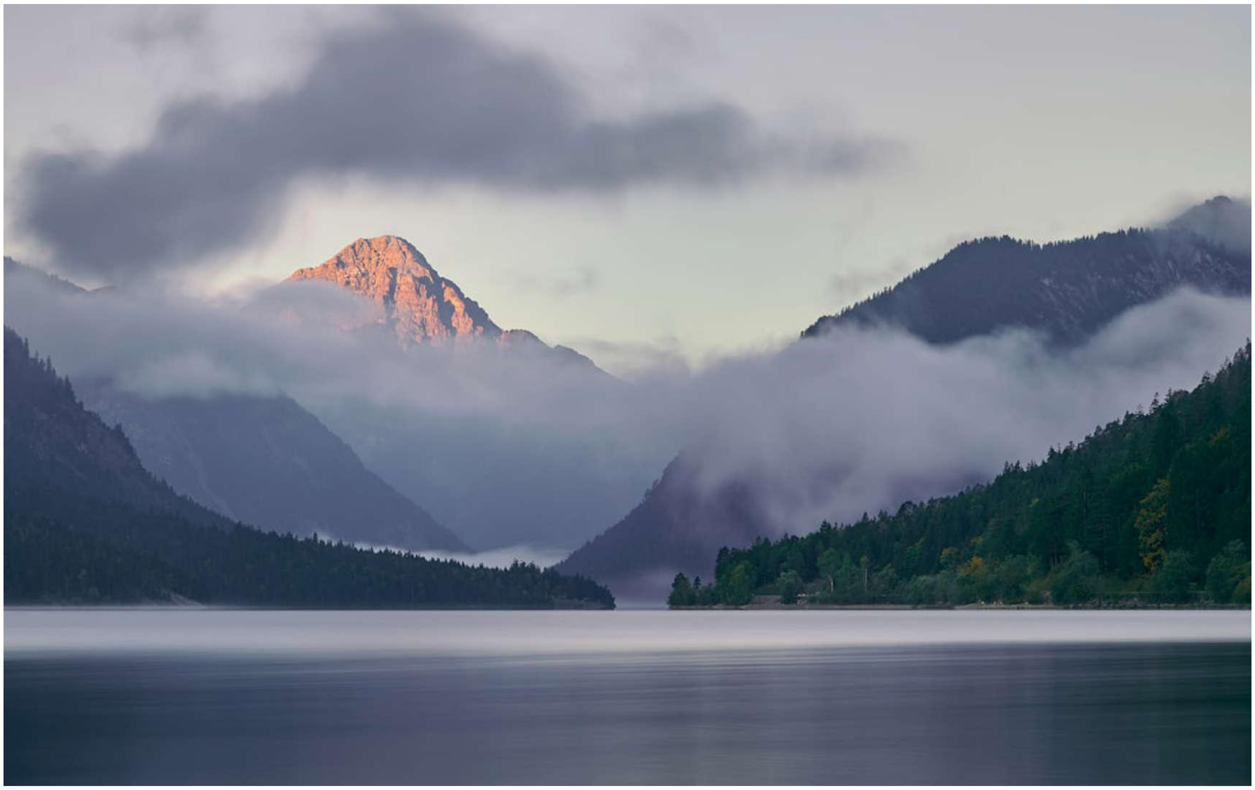
As beings capable of introspection and self-awareness, humans occupy a unique position in the universe. Our perceptions shape our reality, influencing how we interact with the world around us. If consciousness is indeed a universal force, it suggests that our thoughts and actions have far-reaching consequences. This perspective encourages us to consider the impact of our choices, not just on ourselves but on the interconnected web of existence.

Consciousness and Evolution

Could consciousness have played a role in the evolution of life on Earth? Some theorists propose that the emergence of consciousness was a pivotal moment in the evolutionary timeline, driving the development of increasingly complex organisms. This idea challenges the traditional view of evolution as a purely random process, suggesting instead that consciousness may have guided the course of life in subtle and profound ways.

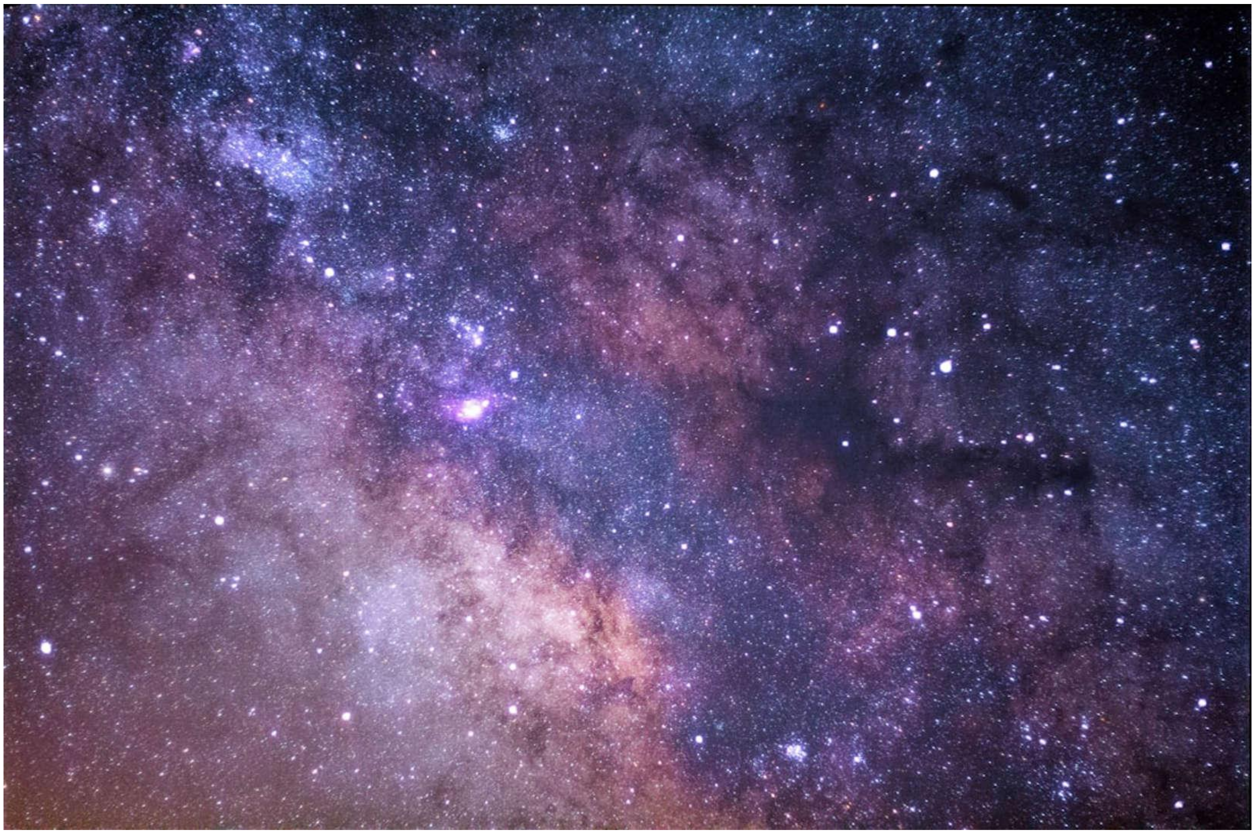
Implications for Artificial Intelligence

As we venture into the realm of artificial intelligence, the question of consciousness becomes increasingly relevant. If consciousness is a universal force, can machines ever truly possess it? This inquiry raises ethical and philosophical dilemmas about the nature of AI and its potential impact on society. Understanding consciousness as a fundamental force could reshape our approach to developing intelligent machines, prompting us to consider the deeper implications of creating entities with the capacity for awareness.



Consciousness Beyond Earth

The search for extraterrestrial life has captivated humanity for generations. If consciousness is a universal force, could it exist elsewhere in the universe? This possibility expands our understanding of life and consciousness, suggesting that the universe may be teeming with awareness in forms we have yet to imagine. The idea that consciousness could be a common thread connecting all life invites us to explore the cosmos with an open mind and a sense of wonder.



Mind Over Matter: A New Paradigm

Embracing the idea that consciousness is a universal force requires a paradigm shift in our understanding of reality. It challenges the notion that the physical world is the ultimate reality, suggesting instead that mind and matter are intertwined in ways we are only beginning to comprehend. This shift opens new avenues for exploration, inviting scientists, philosophers, and curious minds alike to delve deeper into the mysteries of consciousness and its role in shaping the universe.

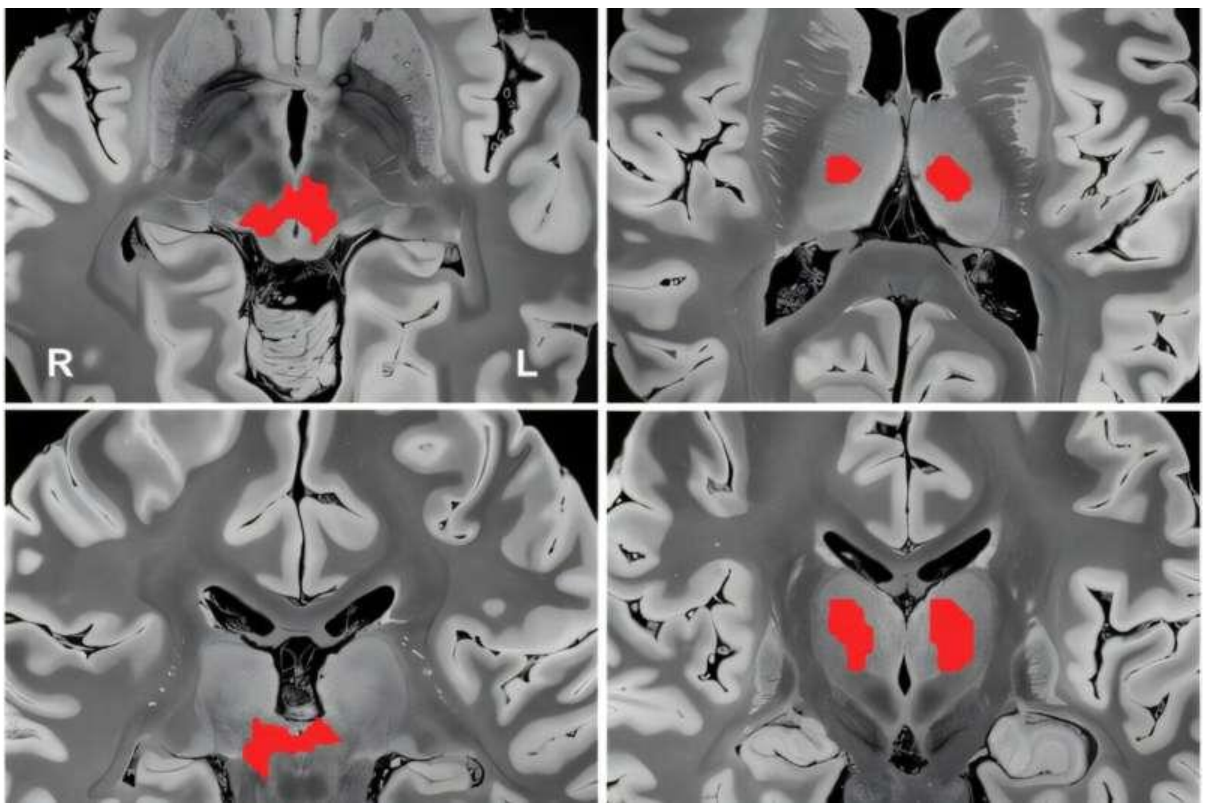
The Journey of Exploration

The notion that consciousness is a universal force invites us on a journey of exploration and discovery. It encourages us to question long-held assumptions and to seek new insights into the nature of reality. Whether through scientific inquiry, philosophical reflection, or personal introspection, the quest to understand consciousness as a fundamental force holds the promise of unlocking profound truths about ourselves and the universe. This journey is not just an intellectual pursuit but a call to embrace the mystery and wonder of existence.

MAY 15, 2025

Deep brain regions link all senses to consciousness, study finds

by Karen Guzman, Yale University



Midbrain and central thalamus show shared subcortical early activations (increases), observed in 11 tasks across four sensory modalities, including, vision, audition, taste, and touch. Credit: *NeuroImage* (2025). DOI: 10.1016/j.neuroimage.2025.121224

A Yale-led study shows that the senses stimulate a region of the brain that controls consciousness—a finding that might inform treatment for disorders related to attention, arousal, and more.

Humans perceive and navigate the world around us with the help of our five senses: sight, hearing, touch, taste and smell. And while scientists have long known that these different senses activate different parts of the brain, a new Yale-led study indicates that multiple senses all stimulate a critical region deep in the brain that controls consciousness.

The study, published in the journal *NeuroImage*, sheds new light on how sensory perception works in the brain and may fuel the development of therapies to treat disorders involving attention, arousal, and consciousness.

In the study, a research team led by Yale's Aya Khalaf focused on the workings of subcortical arousal systems, brain structure networks that play a crucial role in regulating sleep-wake states. Previous studies on patients with disorders of consciousness—such as coma or epilepsy—have confirmed the influence of these systems on states of consciousness.

But prior research has been largely limited to tracking individual senses. For the new study, researchers asked if stimuli from multiple senses share the same subcortical arousal networks. They also looked at how shifts in a subject's attention might affect these networks.

For the study, researchers analyzed fMRI (functional magnetic resonance imaging) datasets collected from 1,561 healthy adult participants as they performed 11 different tasks using four senses: vision, audition, taste, and touch.

They made two important discoveries: that sensory input does make use of shared subcortical systems and, more surprisingly, that all input—regardless of which sense delivered the signal—stimulates activity in two deep brain regions, the midbrain reticular formation and the central thalamus, when a subject is sharply focused on the senses.

The key to stimulating the critical central brain regions, they found, were the sudden shifts in attention demanded by the tasks.

"We were expecting to find activity on shared networks, but when we saw all the senses light up the same central brain regions while a test subject was focusing, it was really astonishing," said Khalaf, a postdoctoral associate in neurology at Yale School of Medicine and lead author of the study.

The discovery highlighted how key these central brain regions are in regulating not only disorders of consciousness, but also conditions that impact attention and focus, such as attention deficit hyperactivity disorder. This finding could lead to better targeted medications and brain stimulation techniques for patients.

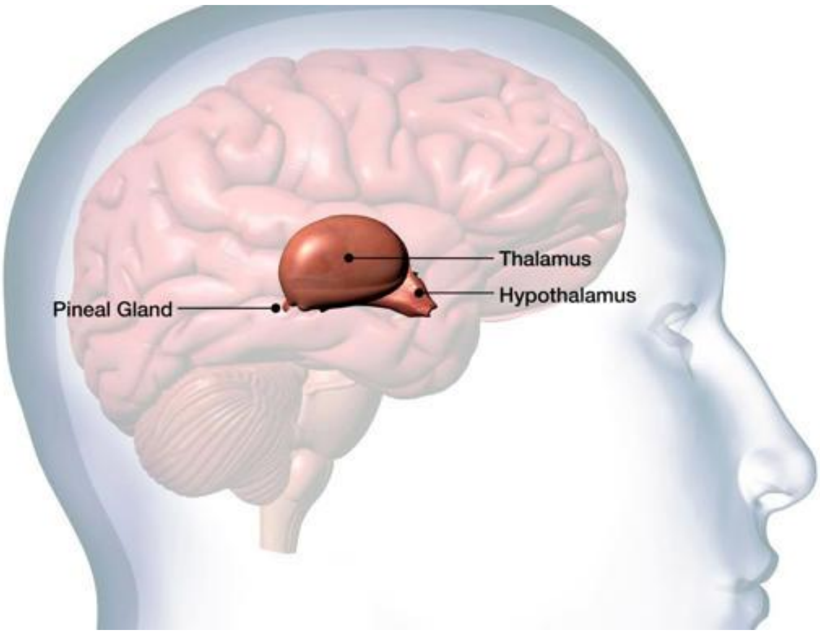
"This has also given us insights into how things work normally in the brain," said senior author Hal Blumenfeld, the Mark Loughridge and Michele Williams Professor of Neurology who is also a professor in neuroscience and neurosurgery and director of the Yale Clinical Neuroscience Imaging Center. "It's really a step forward in our understanding of awareness and consciousness."

Looking across senses, this is the first time researchers have seen a result like this, said Khalaf, who is also part of Blumenfeld's lab.

"It tells us how important this brain region is and what it could mean in efforts to restore consciousness," she said.

More information: Aya Khalaf et al, Shared subcortical arousal systems across sensory modalities during transient modulation of attention, *NeuroImage* (2025). DOI: 10.1016/j.neuroimage.2025.121224
Journal information: NeuroImage
Provided by Yale University

Neuroscientists identify key gatekeeper of human consciousness



A new study published in *Science* has identified the thalamus as a central player in how humans become consciously aware of visual information. By recording electrical activity directly from the brains of five patients during a visual task, scientists discovered that specific thalamic regions activate earlier and more strongly during moments of visual awareness. These findings suggest that the intralaminar and medial thalamic nuclei act as a gateway that initiates conscious pThe thalamus is a small, egg-shaped structure located deep in the center of the brain. It acts as a hub for relaying sensory information—like sight, sound, and touch—to the cerebral cortex, where perception and interpretation occur. In addition to this relay role, it also helps regulate alertness, sleep, and attention.

While the thalamus has long been understood as a relay station for sensory information, it has been largely viewed as a supporting actor—important for maintaining wakefulness, but not the actual source of conscious experience. The current study challenges this idea, offering new evidence that the thalamus does more than just relay signals. It may actively shape what enters our conscious awareness.

To investigate this, the research team took advantage of a unique opportunity to record deep brain activity in humans. Five adult men undergoing treatment for severe, drug-resistant headaches had stereoelectroencephalography (sEEG) electrodes implanted in their brains. These electrodes allowed researchers to monitor neural activity in real-time across multiple brain regions, including various parts of the thalamus and the prefrontal cortex.

Participants completed a visual awareness task that presented images at the edge of conscious visibility. On each trial, a patterned stimulus briefly appeared to one side of a central fixation point. Some images were bright and clearly visible, while others were faint and difficult to detect. Occasionally, no stimulus was shown at all. After each trial, participants responded with an eye movement indicating whether they had seen the stimulus and where it had appeared.

This setup allowed the researchers to compare brain activity between trials where participants consciously saw the stimulus and trials where they did not, even though the visual input was nearly identical. This critical contrast helped isolate the neural processes specifically linked to awareness, rather than simple sensory input.

The results showed that certain regions deep within the thalamus—specifically the central medial nucleus, mediodorsal medial nucleus, and parafascicular nucleus—showed increased activity during trials when participants reported seeing the stimulus. These regions are known as the intralaminar and medial thalamic nuclei. Their responses occurred earlier and with greater intensity than activity in other thalamic regions, such as the ventral nuclei, and even earlier than responses in the prefrontal cortex.

Using a range of analyses, the researchers found that these high-order thalamic nuclei exhibited stronger electrical signals, increased low-frequency oscillations, and more synchronized activity during moments of awareness. Importantly, the timing of this activity—beginning around 200 milliseconds after stimulus presentation—aligned with the earliest known brain signatures of conscious perception, such as the visual awareness negativity signal recorded in prior scalp-based studies.

To understand how these signals travel through the brain, the researchers examined how different brain regions communicated during conscious versus unconscious trials. They measured the synchronization of neural oscillations, particularly in the theta frequency range (about 4–8 Hz), which has been linked to cognitive control and awareness. They also analyzed cross-frequency coupling, which describes how slow brain rhythms may coordinate faster activity in other areas. Both measures revealed that the intralaminar and medial thalamic regions drove neural coordination with the prefrontal cortex during conscious perception.

In other words, when participants were aware of the stimulus, the thalamus was not simply reacting to sensory input—it was actively shaping the brain's response, sending signals to the prefrontal cortex and helping to organize brain-wide activity in support of awareness.

Additional analyses showed that the neural patterns in the thalamus and prefrontal cortex encoded information about whether participants were consciously aware of the stimulus, rather than simply reflecting aspects of the task like contrast strength, motor response, or reaction time. This strengthens the case that these regions are directly involved in conscious perception, rather than just downstream reflections of other cognitive processes.

Interestingly, the researchers also found that the activity in the thalamus, particularly in the intralaminar and medial nuclei, could begin even before the stimulus appeared. This pre-stimulus activity was more synchronized in trials where participants would later report being aware of the stimulus, suggesting that these regions may help set the stage for conscious perception by influencing the brain's state of readiness.

This study is the first to offer such detailed recordings from multiple thalamic nuclei in humans during a task designed to probe the boundary between conscious and unconscious visual perception. Prior studies using imaging methods like functional MRI or magnetoencephalography hinted at thalamic involvement in awareness but lacked the precision to pinpoint when and where this activity occurred. The use of sEEG here provided a rare opportunity to capture the dynamics of deep brain structures with both high temporal and spatial resolution.

The findings provide strong support for the idea that consciousness is not solely a cortical phenomenon. Instead, the thalamus—especially its high-order nuclei—appears to play an active and early role in making sensory information available to our awareness. This may reflect the thalamus's unique position as a hub, with widespread connections to both cortical and subcortical brain regions, allowing it to coordinate complex patterns of neural activity required for consciousness to emerge.

However, the authors note some limitations. The study was conducted in a small sample of five male patients, all of whom had electrodes implanted for clinical reasons related to headache treatment. Although their cognitive abilities and vision were intact, these participants do not represent the general population. Moreover, electrode placement was determined by medical need, not research goals, which means some brain regions may have been under-sampled or missed entirely.

Additionally, while the study strongly suggests that intralaminar and medial thalamic nuclei initiate the conscious perception process, it does not rule out important contributions from the cortex. The prefrontal cortex, particularly the lateral regions, still showed significant activity and participated in synchronized neural networks during awareness. The researchers suggest that the thalamus may act as a gate or initiator, while the cortex elaborates on the content of experience.

The study, "Human high-order thalamic nuclei gate conscious perception through the thalamofrontal loop," was authored by Zepeng Fang, Yuanyuan Dang, An'an Ping, Chenyu Wang, Qianchuan Zhao, Hulin Zhao, Xiaoli Li, and Mingsha Zhang.

Human high-order thalamic nuclei gate conscious perception through the thalamofrontal loop

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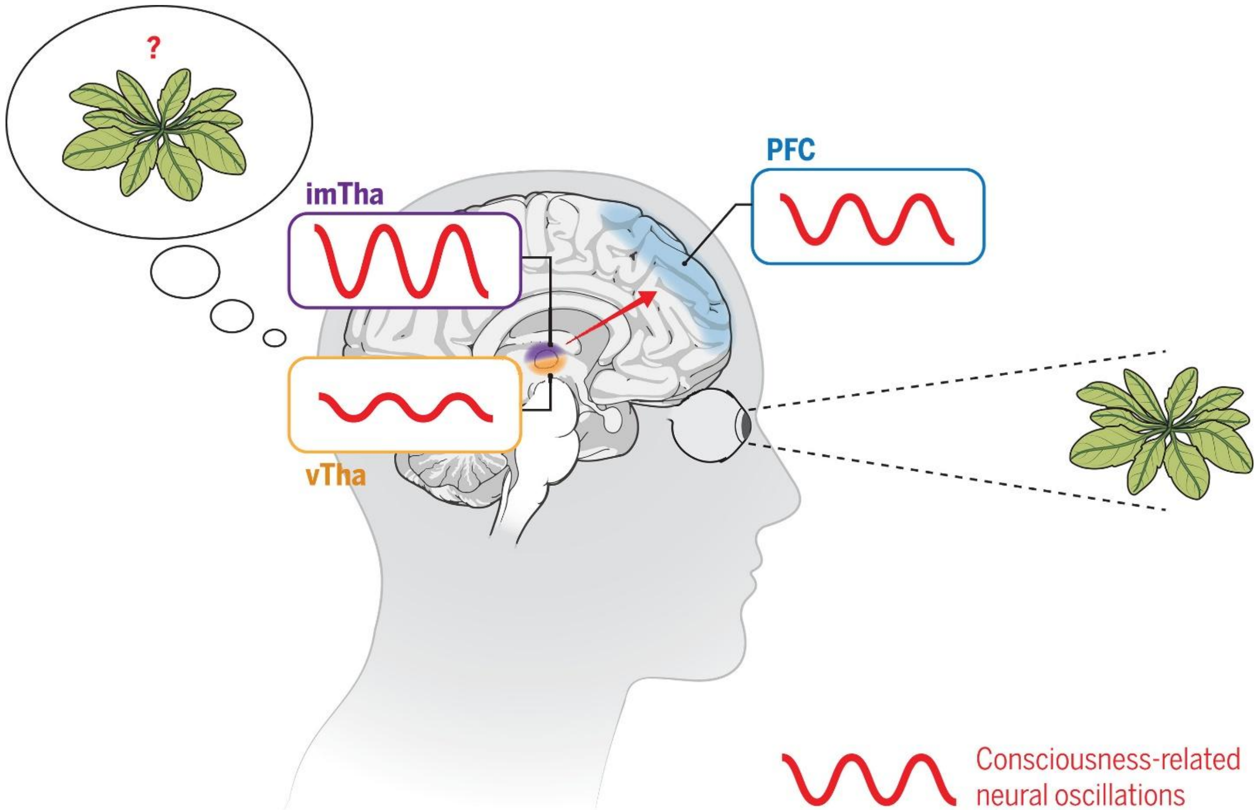
Abstract

Human high-order thalamic nuclei activity is known to closely correlate with conscious states. However, it is not clear how those thalamic nuclei and thalamocortical interactions directly contribute to the transient process of human conscious perception. We simultaneously recorded stereoelectroencephalography data from the thalamic nuclei and prefrontal cortex (PFC), while patients with implanted electrodes performed a visual consciousness task. Compared with the ventral nuclei and PFC, the intralaminar and medial nuclei presented earlier and stronger consciousness-related activity. Transient thalamofrontal neural synchrony and cross-frequency coupling were both driven by the θ phase of the intralaminar and medial nuclei during conscious perception. The intralaminar and medial thalamic nuclei thus play a gate role to drive the activity of the PFC during the emergence of conscious perception.

The intralaminar and medial thalamic nuclei (imTha) play a gate role in human conscious perception. The consciousness-related neural activity in imTha is earlier and stronger than that in ventral nuclei (vTha) and prefrontal cortex (PFC), and consciousness-related information originally flows from imTha to PFC during the emergence of human conscious perception.



Editor’s summary

Most studies investigating the neural correlates of conscious perception have focused on the cerebral cortex, and the functional role of subcortical structures has rarely been explored. It has, however, been proposed that subcortico-cortical loops play a prominent role in conscious perception. Using simultaneous intracranial recordings from human thalamus and prefrontal cortex, Fang *et al*. investigated the neurophysiological correlates of conscious detection and report. Analysis of the oscillatory dynamics of the neural signals suggested that the direction of information flow for neural correlates of consciousness was from the medial and intralaminar thalamus to the prefrontal cortex. These findings indicate that intralaminar and medial thalamic nuclei gate conscious perception. This conclusion is a significant advance in our understanding of the network basis of visual awareness in humans. —Peter Stern

Structured Abstract

INTRODUCTION

Exploring the neural substrates underlying human consciousness is one of the most exciting and challenging tasks in modern science. There are at least two distinct modes of consciousness: the conscious state (awake, asleep, and coma, etc.) and the conscious content (specific conscious experience). Human high-order thalamic nuclei activity is known to closely correlate with conscious states. However, it is not clear how those thalamic nuclei and thalamocortical interactions directly contribute to the transient process (which occurs on a millisecond scale) of human conscious perception. Whereas most studies have focused the search for the neural correlates of conscious perception on the cerebral cortex, relatively few studies have explored the functional role of subcortical structures, including high-order thalamic nuclei. Recently it has been hypothesized that the high-order thalamic nuclei act as gates to modulate cortical activity during conscious perception; however, there is a lack of direct empirical evidence from human studies to support such argument.

RATIONALE

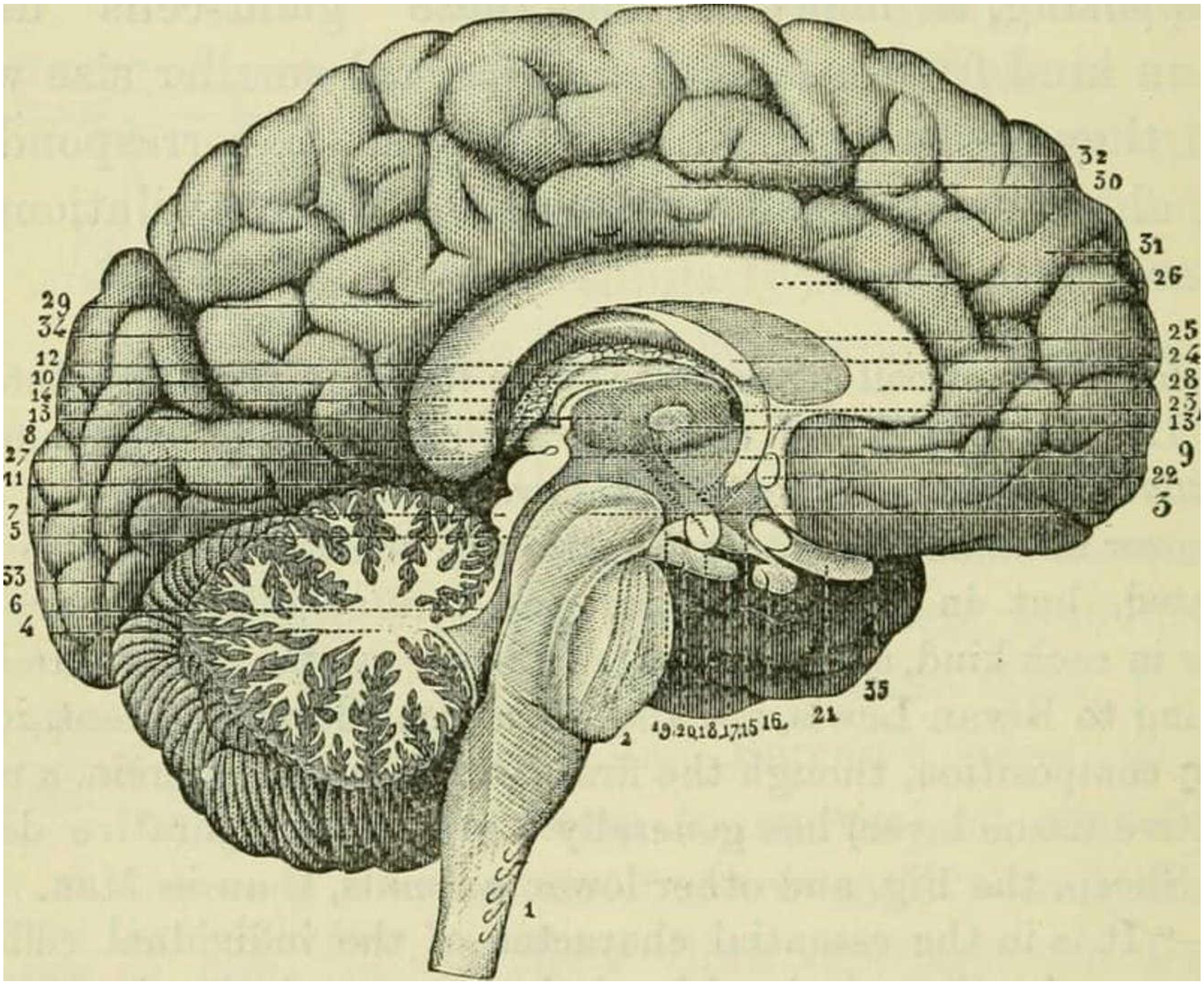
The thalamus has been conventionally assumed to act as a prerequisite of sensory information for conscious perception rather than directly contributing to it. However, this assumption has been challenged by novel theoretical hypothesis and empirical evidence, mostly from anatomy and neuroimaging studies, which have shown the direct involvement of the human thalamus in various cognitive functions. Although several theories of consciousness have proposed that the thalamocortical loops might play a critical role in human conscious perception, it is largely unknown how consciousness-related information is processed and transferred within these loops. Moreover, because there is great functional heterogeneity across thalamic nuclei, it is necessary to identify the respective roles of different thalamic nucleus in conscious perception. However, precisely capturing neural activity with high spatial and temporal resolution in human thalamic nuclei and in thalamocortical loops is very difficult owing to technical restrictions. Simultaneous intracranial recordings from human thalamic nuclei and thalamocortical loops provide an excellent opportunity to elucidate the dynamic process of thalamocortical loops during the emergence of conscious perception.

RESULTS

We simultaneously recorded stereoelectroencephalography (sEEG) data from multiple thalamic nuclei and prefrontal cortex (PFC) while patients were performing a novel visual consciousness task. In this task, the matched saccadic response between the conscious and unconscious conditions largely minimized the confusion of report-related activity with consciousness-related activity. Compared with the ventral nuclei and PFC, the intralaminar and medial nuclei presented earlier and stronger consciousness-related activity, including both event-related potential (ERP) and event-related spectral perturbation (ERSP). Transient thalamofrontal neural synchrony and cross-frequency coupling were both driven by the θ phase (2 to 8 Hz) of the activity in intralaminar and medial nuclei during the emergence of conscious perception. The coupling between these two thalamic nuclei and lateral PFC (LPFC) was stronger than that between these nuclei and other PFC subregions during conscious perception. Further decoding analysis of the stimulus-evoked activity in the intralaminar and medial nuclei and LPFC showed that the accuracy was highest when decoding conscious perception (conscious versus unconscious) compared with decoding other task-related events (such as stimulus contrast, rule cues, saccade direction, and saccade reaction time).

CONCLUSION

We provide direct sEEG evidence in the human brain that supports the gate role of the intralaminar and medial nuclei in the rapid process of conscious perception. More specifically, the intralaminar and medial nuclei play a more important role than the ventral nuclei during the emergence of conscious perception. The interaction between the LPFC and intralaminar and medial nuclei, which originates from the intralaminar and medial nuclei, may play an essential role during conscious perception. Moreover, the stimulus-evoked activity in the thalamofrontal loop primarily encodes consciousness-related information rather than other task-relevant events. These results support the argument that the intralaminar and medial thalamic nuclei play a gate role to modulate the activity of PFC during the emergence of conscious perception.



The Mystery of Consciousness

"An intricate visualization of the human mind, highlighting the complex networks of consciousness within the brain."

The rise of **consciousness** from non-living matter is a profound enigma that continues to challenge scientists and philosophers. How do physical processes give rise to self-awareness and subjective experience? Some thinkers suggest that consciousness itself may be a fundamental aspect of reality, possibly pointing to a divine source or creative principle woven into the universe. This enduring mystery connects fields like neuroscience, philosophy, and cosmology