ISSUE 49 Fall 2021

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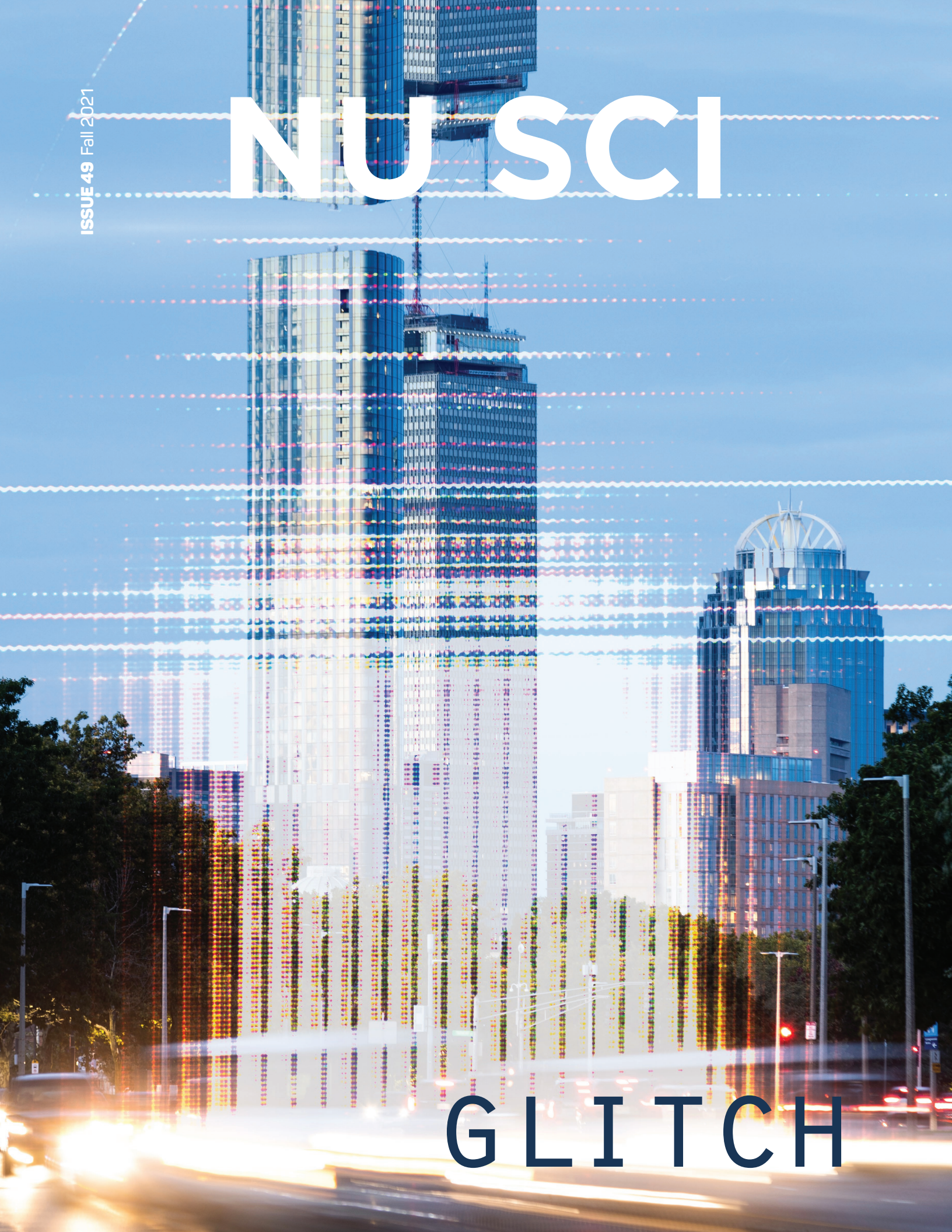

GLITCH

Fall 2021

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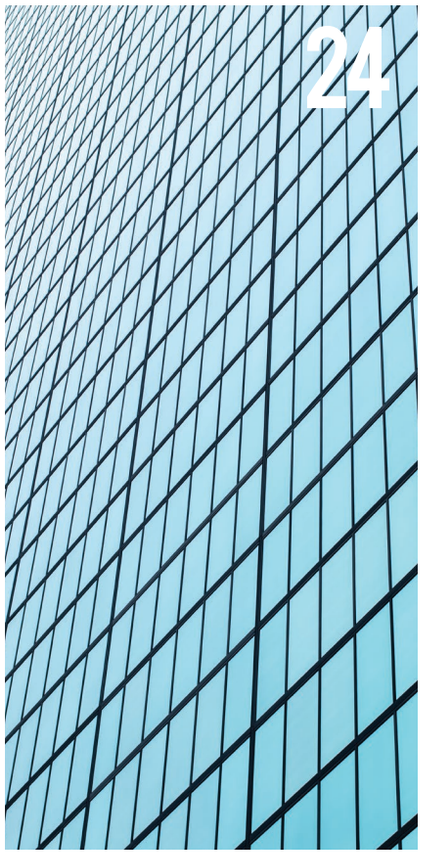

LETTER FROM THE EDITOR

Nothing in life is perfect, including the universe. In the fabric of reality, a computer screen, or your brain, there are wrinkles that don't sit quite right for a moment or two. Sometimes, you forget why you're in a room, or sometimes, you can't access an email. That glitch throws off the smooth progress of your life. But sometimes, that glitch causes something incredible to happen. The dark corners of the ocean glow with living light, a new species gets identified, or a novel insight into our universe is discovered.

From the trivial to the titanic, accidents, surprises, and oddities make us question the world around us; they fuel our pursuit of knowledge and spark our curiosity. The thing about glitches is that you can't help but notice when they're there. They catch your eye, and this issue showcases all the glitches that have caught our eyes.

Back to another year of in-person classes and co-ops, for most of us, we're more than happy to start going back to some semblance of normalcy, and we're more than happy to present another issue with our phenomenal writers, designers, photographers, and editors.

As we return to routines, notice the glitches that stop you for a moment, and don't just notice them but take a closer look at them and see what insights they can offer you too. You could find hidden inconveniences or happy little accidents.

Until then, enjoy the insights our writers have to offer in "Glitch."

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COVER PHOTOS BY IAN HAY

GLITCHING OUT IN THE FACE OF FEAR

BY AMANDA BELL, DATA SCIENCE & BEHAVIORAL NEUROSCIENCE, 2023

There's a trail of red arrows extending along the carpeted floor toward a white tent with two openings, a trace of rubbing alcohol lingers in the air, and Whitney Houston's "I Wanna Dance with Somebody" is playing over the speakers dotted along the speckled tile ceiling when, suddenly, there are two faint thuds to the right of the white tent. Someone calls frantically for an employee who comes bearing water for a dazed woman lying on the carpeted floor next to a plastic chair. Another person says that the woman fainted off the chair shortly after sitting down again following an injection of the COVID-19 vaccine. In the medical world, there's another word for this: vasovagal syncope.

Vasovagal refers to a reaction directed by the vagus nerve, a major component of the parasympathetic nervous system, where heart rate decreases and blood vessels in the legs widen. Syncope, otherwise known as fainting, is defined as a brief loss of consciousness — with vasovagal syncope being the most frequent type, according to a December 2014 article published in *Frontiers in Physiology*. It happens when the sympathetic nervous system has an exaggerated response to a perceived threat, sending the body into fight-or-flight mode. The parasympathetic nervous system, which calms the body, overcompensates for the response, resulting in the loss of consciousness.

A September 2014 review in *Frontiers in Physiology* identified three stages at the onset of vasovagal syncope based on physiological indicators including heart rate, blood pressure, and nerve activity. During the first stage, mutual increases in sympathetic nerve and vagus nerve activity maintain blood pressure. Sympathetic nerve activity increases to respond to the present threat, leading to a rise in blood pressure. Then, the parasympathetic nervous system dilates blood vessels to decrease blood pressure, and this fluctuation continues until stage two when heart rate increases to counteract the falling blood pressure. In stage two, parasympathetic nerve activity starts to overwhelm sympathetic nerve activity, forcing the sympathetic nervous system to increase its response. Stage two begins when the sympathetic nervous system can no longer compensate for the blood pooling in the lower body by increasing blood pressure or heart rate, so blood flow to the heart remains low. The sympathetic nervous system then raises the amount of air the lungs take in to increase blood flow back to the heart, but this too fails. Because the heart is pumping less blood, blood pressure decreases, and sympathetic nerves increase heart rate again. Stage three occurs when the vagus nerve suddenly and significantly lowers heart rate, and sympathetic nerve activity stops. This results in an immediate drop in blood pressure as well as potential cardiac arrest, cold sweat, nausea, and ultimately fainting when the brain doesn't receive enough oxygen.

Given these processes that lead to fainting, how can vasovagal syncope be prevented? If blood pooling in the lower body makes it more difficult for blood pressure and heart rate to be maintained in stage two, then either blood flow towards the heart needs to be increased or blood pressure and heart rate maintenance needs to be aided manually. To increase blood flow back to the heart, someone at risk of fainting should lie down completely (i.e., not sit down) because lying down will redistribute blood evenly throughout the body. To maintain blood pressure and heart rate, someone could tense their muscles, repeatedly cross and uncross their legs, or squeeze their hands because tensing could prevent the sudden drop in heart rate and blood pressure that leads to passing out. Another suggestion in the *Permanente Journal* to prevent fainting is hydrating and staying hydrated. When someone is dehydrated, blood volume drops, which decreases blood pressure and makes it easier to pass out.

Unfortunately, situations like the one where the woman passed out after receiving a vaccination are quite common, but using the strategies described can make them less frightening. If you or someone near you passes out, ensure that they remain lying on their back for a few minutes before slowly getting up to prevent fainting again. In the less common cases where someone isn't breathing, doesn't regain consciousness within one minute, has a head injury, or shows signs of a stroke, call 911 or a local emergency number. Otherwise, having water, juice, or a light salty or sugary snack on hand can be beneficial to someone who passed out once they fully regain consciousness. Even though the nervous system can glitch out in syncope-inducing situations, that doesn't mean you have to.

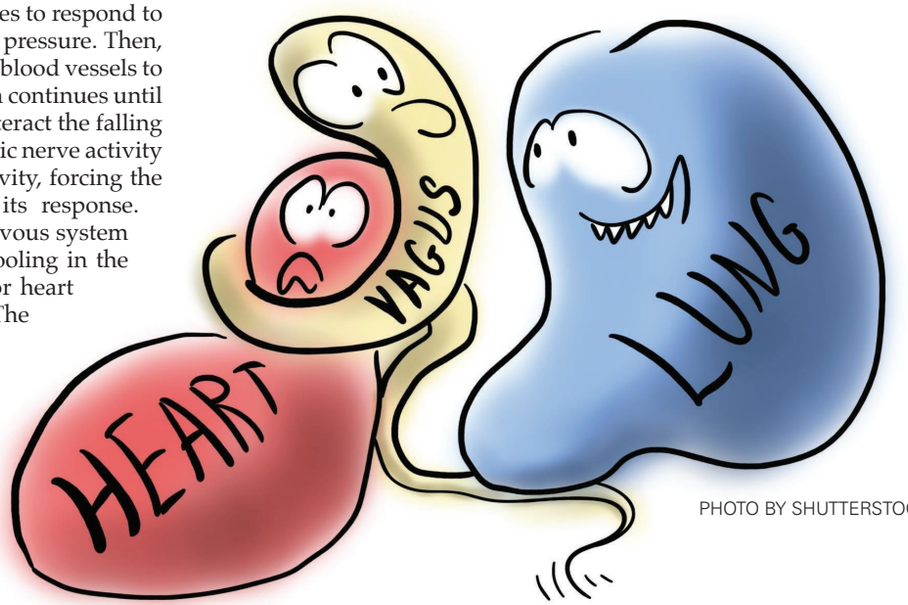


PHOTO BY SHUTTERSTOCK

DESIGN BY YECHAN YANG, BEHAVIORAL NEUROSCIENCE, 2022

Front Physiol. (2014). DOI: 10.3389/fphys.2014.00471
Perm J. (2019). DOI: 10.7812/TPP/17-136
Front Physiol. (2014). DOI: 10.3389/fphys.2014.00343

SLIME MOLD

The cell that's smarter than you

ARTICLE AND DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

As you walk across campus on a warm fall day, you pass by what looks like a small, bright yellow chunk of coral rising up from under some mulch. A few days later as you walk the same route — do you remember it correctly, or did that yellow mushroom-like blob move?

That blob is no mushroom. Called slime mold, this single-celled plasmodial organism can move in search of food — unlike any mushroom — and is classified with the Kingdom Protista. Most plasmodial slime molds are only a few centimeters wide, but a few may grow up to a foot in diameter. Somehow, they are still composed of only one cell. Unlike other cells, which contain one nucleus, this cell contains millions. And though it has no brain, it can definitely outcompete you in a mathematical processing contest.

How do we know this plasmodial cell can compute problems? Scientists have seen a single slime mold solve the same problems challenging teams of human mathematicians and engineers. They solve complex "shortest path" problems linking thousands of points together, which are challenging to solve even for a computer. are challenging algorithms to solve for both humans and computers. All of this is based on slime mold's decision-making skills while it searches for food and avoids adverse conditions, like strong light. Slime mold can also anticipate periodic events and habituation, so it can even adapt to and learn from new environments. To look for food, the main cell sends out "reconnaissance branches," and if these branches find something to eat, the slime mold surrounds the food and creates ropy tunnels to transmit nutrients. This creates a matrix of branches. By substituting food with the concept of "a population" and light with "obstacles," researchers found that slime mold can create a complex map.

In an experiment, researchers from Hokkaido, Japan placed oat flakes — a favorite food — in a pattern that imitated population-dense centers in Japan. As the slime mold spread over the piles of oat flakes, it stretched and morphed using its nutrient-carrying branches. After a few hours, a familiar pattern formed. The brainless cell created a network that nearly mirrored that of the Japanese rail system.

While replicating transit systems is a cool parlor trick, slime mold researchers are working on mapping things on an infinitely larger scale. Instead of cities, slime mold is linking galaxies in a new 3D model to better understand how the galaxy-connecting cosmic web is woven.

The cosmic web is perhaps the largest structure in the universe. It is made of a web of dark matter and gas connecting and fueling stars. However, we don't exactly know where much of it is located. This matter is either too spread out — because of the nature of dark matter — "too dark" to show up widely in imaging, knowledge of its layout is limited.

> "Scientists have seen a single slime mold solve the same problems challenging teams of human mathematicians and engineers."

A group of researchers created a computer algorithm following slime mold's behavior. Then, they applied data from the Sloan Digital Sky Survey which contained the locations of 37,000 galaxies. The algorithm created a 3D map linking these galaxies. The team then pointed telescopes at locations predicted to contain pieces of the cosmic web. Analyzing the UV light indicated hydrogen gas far away from other galaxies. This means the model accurately predicted where the cosmic web is located.

"You can almost see, especially in the map of galaxies in the local universe from the Sloan data, where the filaments should be," lead researcher Joseph Burchett of the University of California, Santa Cruz said in a NASA press release. "The slime-mold model fits that intuition impressively. The structure that you know should be there is all of a sudden found by the computer algorithm."

This biological model has been suggested for solving medical problems too, like modeling the way blood vessels grow around tumors. With slime mold generating brillant biological models, we may be able to understand a little more about our universe.

The Astrophysical Journal Letters (2020). DOI: 10.3847/2041-8213/ab700c
Science (2010). DOI:10.1126/science.1177894

PHOTO BY FLICKR

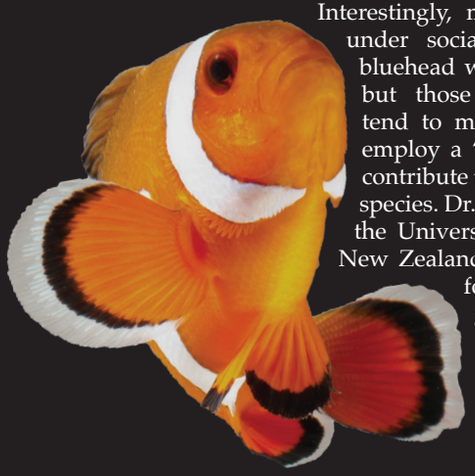
"Supermales" and social groups:
What we know about sex-changing organisms

BY EMMA TUSUZIAN, PSYCHOLOGY, 2023
DESIGN BY KAI GRAVEL-PUCILLO, PSYCHOLOGY, 2022

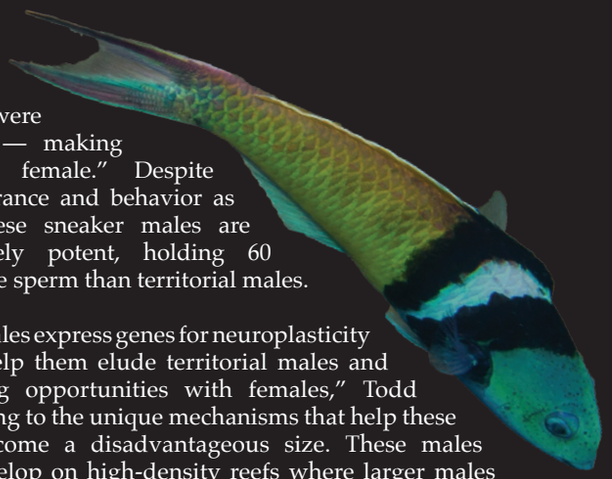
What if "male" and "female" were only temporary states? In the worlds of fish, snails, and slugs, animals can have sexual plasticity: the ability to shift between sexes throughout their lives. Also known as sequential hermaphroditism, the advantages and costs of this reproductive strategy remain debated. There are two main types of sequential hermaphroditism: protogyny, in which organisms born female change their sex to male as they mature, and protandry, in which organisms begin life as male and mature to be female. Though sequential hermaphroditism is rare, evaluating the underlying reasons for these changing biological functions can help understand evolutionary sex change, mating systems, and social structures.

The most common form of sequential hermaphroditism is protogyny, which is driven by male size advantage. According to the size advantage model, sexual change is adaptive when reproductive success is greater as one sex when smaller and another sex when older (and often larger). Therefore, the timing of the sex change ensures optimal reproductive success over the organism's lifetime. Typically, this change occurs later in life in response to internal or external triggers. Since male reproductive success increases with age and it is thought to be advantageous for a male organism's body to be larger, this sex change promotes reproductive success longer in life.

Bluehead wrasse are highly social and polygamous fish that school in thousands in the reefs of the Atlantic Ocean. Their coloration varies throughout their lifetime, but they get their name from their "supermale" form, featuring a bright blue head, three stripes of black and white, and a golden body. As prime examples of protogynous animals, only a small percentage of males — or females who become males — reach this final phase. Dominant males take the role of defending egg spawning sites, where females often stay. When a dominant male is lost, sex change is stimulated in the largest female of the social group. This comes with rapidly increasing aggressive and male-typical courtship behavior, anatomical changes, and coloration into the supermale form after which they are named. In just 10 days, the largest females become fertile males.



Interestingly, male development is also under social control. Most juvenile bluehead wrasse develop as females, but those that develop as males tend to mimic females and instead employ a "sneaker" mating tactic to contribute to the development of their species. Dr. Erica Todd, a researcher at the University of Otago in Dunedin, New Zealand studying sneaker males, found that "many of the genes critical for male sex hormone production were turned off — making them look female." Despite their appearance and behavior as females, these sneaker males are reproductively potent, holding 60 percent more sperm than territorial males.



"Sneaker males express genes for neuroplasticity that may help them elude territorial males and steal mating opportunities with females," Todd said, speaking to the unique mechanisms that help these males overcome a disadvantageous size. These males tend to develop on high-density reefs where larger males are less effective at dominating mating opportunities than usual. The dynamic of bluehead wrasse males, like in many other protogynous species, includes dominant supermales who use territorial aggression to monopolize matings and smaller sneaker males whose physiology allows them to steal these mating opportunities.

Protandry, on the other hand, favors a female-biased reproductive size advantage. This phenomenon is less common than protogyny and is usually associated with mating systems without male territorial defense or sperm competition, such as monogamous or random mating systems. As an inverse to the male size advantage of protogyny, the positive relationship between female fertility and body size makes male-to-female sex change more adaptive.

Clownfish are commonly studied as examples of protandrous sex change. Each social group holds one monogamous mating pair and smaller, sexually immature males. When the dominant female is lost, it prompts her partner, the largest male in the group, to change into the female sex. It also prompts the maturation of the most dominant, immature fish as the new breeding male. Due to limited habitat space in sea anemones, body size is restricted, and there is greater reproductive value if the larger fish of the pair is female.

Despite numerous studies on sequentially hermaphroditic species, underlying causes and explanations for these behaviors are still largely theoretical. What impacts does social control have on genetic expression of characteristics or functions? Could sequential hermaphroditism be stimulated in other species under certain conditions? Many exciting questions remain unanswered about this fascinating phenomenon that may shed light on how sex evolves among species.

Sexual Development (2016). DOI: 10.1159/000449297
Scientific Reports (2016). DOI: 10.1038/srep29439
Molecular Biology and Evolution (2017). DOI: 10.1093/molbev/msx293

PHOTOS BY SHUTTERSTOCK

CURING OLD AGE:

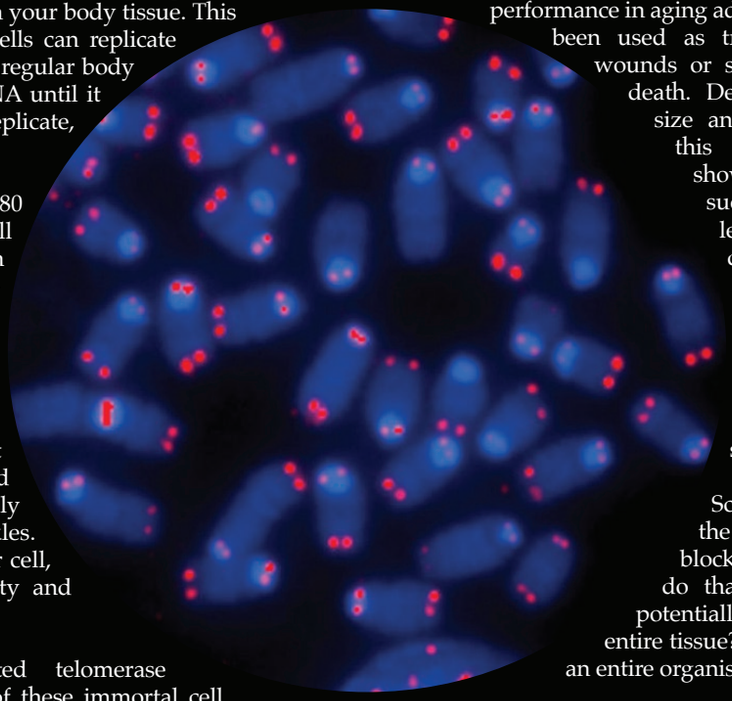
HOW GENETIC REGENERATION COULD TURN BACK THE CLOCK

BY CLAIRE MA, HEALTH SCIENCE, 2025

DESIGN BY NICOLE COHEN, CELL & MOLECULAR BIOLOGY, 2025

While wrinkle creams and wheatgrass shots may be all the anti-aging rage, the real secret lies within all of us. Put simply, aging is the slow progression of DNA damage. As cells replicate, approximately 100 base pairs of DNA are lost in what is known as the end-replication problem. Organisms have long developed a counter for this: telomeres and telomerase.

Telomeres are repeating sequences of nucleotides found at the ends of chromosomes, and telomerase is the enzyme that regenerates them. Together, they protect the contents of your coding DNA so no important sequence or function is lost via cell replication. This may seem too good to be true, but telomerase is only active in regular germ cells in order to protect the vital DNA that produces offspring and not active in the regular somatic cells in your body tissue. This means that while germ cells can replicate without losing any DNA, regular body tissue will slowly lose DNA until it becomes too damaged to replicate, a stage called senescence.



After about 60–80 population doublings, all somatic cells will reach a stage of senescence — they are still allowed to perform their metabolic functions but are unable to replicate. This effect shows up as regular signs of aging, including but not limited to weakened tissue, less efficient bodily functions, and wrinkles. Some cells, like the cancer cell, have achieved immortality and never become senescent.

Scientists have correlated telomerase activity to the longevity of these immortal cell lines, as close to 95 percent of immortal cell lines and 85 percent of cancers show sustained telomerase activity. The 5 percent that don't utilize telomerase instead utilize the alternative lengthening of telomeres technique (ALT) that prevents telomere shortening by looping the broken DNA segment back onto previous nucleotides to repair the telomeres, which works because of the telomere's repeating nature.

Ever since the role telomerase plays in the survival of cancer was discovered, scientists have been seeking ways to stimulate telomere regeneration in regular cells. And recently, those efforts have paid off.

In 2011, authors of a year-long deep-sea diver study hypothesized that their high-pressure environment would induce oxidative stress on the divers, which is suspected to be the leading factor in telomere shortening. Instead, they were greeted with data that showed telomere elongation in both the participants' blood cells. The authors wrote their conclusion in tones of disbelief, with their primary explanation for their results being "a random or systematic technical measurement inaccuracy."

On the contrary, the Tel Aviv University Sackler School of Medicine proved that this was no mistake. A group of 30 individuals were exposed to a treatment called hyperbaric oxygen therapy (HBOT), which is 100 percent oxygen delivered under high pressure, similar to the conditions the scuba divers were subject to. Previously, the same research team found that HBOT was able to enhance cognitive performance in aging adults. It also had previously been used as treatment for non-healing wounds or situations involving tissue death. Despite their small sample size and lack of control group, this preliminary research showed staggering results of successful, in vivo telomere lengthening like that of the divers' study. After regular HBOT sessions, leukocytes of the participants had experienced telomere lengthening of up to 38 percent, with a decrease of up to 37 percent of senescent cells.

Scientists are turning back the clock on the building blocks of our being. If we could do that to one cell, could we potentially turn back the clock on an entire tissue? An entire organ? Or even an entire organism?

Will this be worth pursuing as a vanity project? For now, no. At least not for most of us. Most of this regenerative treatment will most likely go towards helping those with genetic aging disorders. But it raises the question — have we unlocked the secret to biological "immortality?" And would the advent of this discovery lead us to a dystopia synonymous to the designer baby world of the movie "GATTACA," or would this lead us to a cutting-edge cure for aging?

Mechanisms of Ageing and Development (2011). DOI: 10.1016/j.mad.2011.01.005.
Aging (2020). DOI: 10.18632/aging.202188.
Biomolecules (2020). DOI: 10.3390/biom10060958.
The FASEB Journal (2015). DOI: 10.1096/fj.14-259531

PHOTO BY FLICKR

Bionic eyes

Can we provide artificial vision?

BY WALI SIDDIQUI, BIOENGINEERING, 2025

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

An estimated 45 million people in the world are blind. A multitude of factors cause blindness. Amongst the greatest are genetic disorders, such as retinitis pigmentosa, which affects over 2 million people worldwide, and macular degeneration, which affects 14 percent of people over the age of 80. One solution to this? Bionic eyes.

Creating artificial vision through the use of bionic eyes is no longer science fiction. The emergence of prosthetic limbs paved the way for scientists to experiment with prosthetic eyes. While a vast number of designs and variations are being pursued, they all target genetic blindness and create vision through electrical stimulation.

To understand how bionic eyes work, one must understand what causes most genetic blindness. Vision loss is often attributed to the progressive degeneration of photoreceptors located on the outside of the retina. Photoreceptors are tightly packed membranes containing the photopigment rhodopsin. When light hits it, a series of chemical reactions stimulates your retina and sends electrical signals to your brain, creating vision. When photoreceptors become dysfunctional, the light that goes into our eyes can't be converted into electrical signals, causing blindness.

That's where bionic eyes come into play. Bionic eyes are actually just sunglasses with a camera attached to them, not actual artificial eyes. The camera continually captures images, converts them to radio waves, and sends them to the electrode implant in your retina. The implant stimulates the surrounding neurons in your retina, which send the signal along the visual pathway to the brain.

> "[Bionic eyes] create vision through electrical stimulation."

Theoretically, the more electrodes placed in the retina, the more one can electrically stimulate the neurons around it for better vision. However, there is such a thing as too much electrical stimulation. An experiment done by a German company, Retina Implant AG, in 2015 found that an array of 100 electrodes produced worse vision in their subjects compared to those with an array of 64 electrodes. The issue is that when one stimulates the neurons in one area of the visual pathway too much, vision starts to get blurry and fuzzy, making bionic eyes difficult and intricate to advance.

The bionic eyes we have today provide minimal, yet definitive vision to those visually impaired. Improving them will be difficult, but scientists have done the impossible in the past, so there is hope they can do it in the future as well.

Progress in Brain Research (2011). DOI: 10.1016/B978-0-444-53355-5.00001-4

PHOTO BY MIMI PEREZ, ENVIRONMENTAL STUDIES, 2025

How bioluminescence illuminates our waters

And where it can be applied

ARTICLE AND DESIGN BY JESSICA HEALEY,
MECHANICAL ENGINEERING, 2024

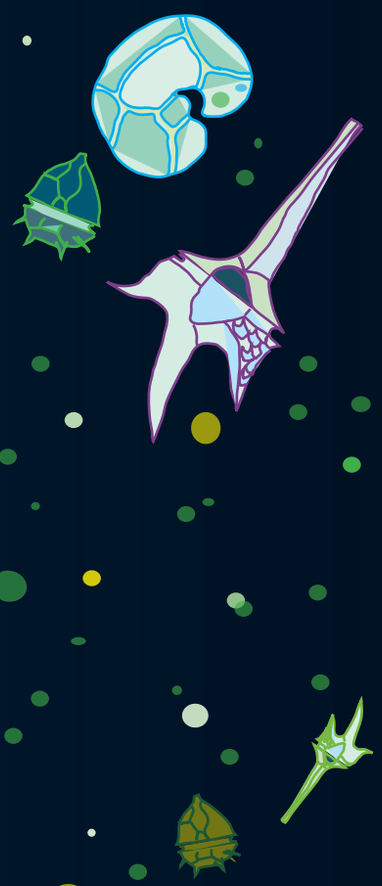
Most people would turn to unnatural explanations when water and animals illuminate the night. In reality, organisms can chemically produce this light on their own. This phenomenon, called bioluminescence, occurs in organisms such as bacteria, algae, plankton, crustaceans, and even fish. But what generates the ethereal glow and why?

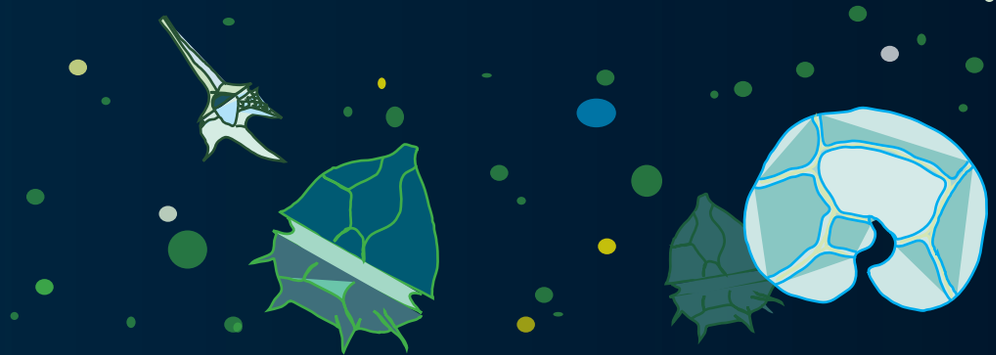
Bioluminescence occurs when a light-emitting molecule called a luciferin becomes oxidized in the presence of a catalyzing enzyme. Photoproteins, a type of light-producing enzyme, are provoked to create light when binding to substances such as Ca2+or Mg2+. Another form of luminescence is bacterial, which also requires a luciferase and oxidation. The light produced through bioluminescence is typically limited to blue-green wavelengths; a protein called aequorin gives off a photon of blue light which is then "absorbed by [a] green fluorescent protein that emits a green photon, so [organisms] appear green" comments Professor Joseph Ayers from the Department of Marine and Environmental Science at Northeastern University. However, animals can adjust the intensity and color of this light through control mechanisms like neurotransmitters.

For animals, their glow can act in their defense, conceal their shadow, stun prey, or act as a form of communication. But bioluminescence can be used by humans too, from detecting harmful algal bloom to ocean modeling. In the field of biotechnology, bioluminescent imaging can perform noninvasive viewing of molecular activity.

Beyond contemporary uses, perhaps speculative solutions to modern issues lie in our oceans. Picture a future that exists inside the waters that humans have barely explored. If waters rise and humans must build communities in conjunction with the ocean, new technologies and designs will be needed. Methods of communication might need to adapt to underwater environments. The sun might have to be replaced with manufactured light such as bioluminescence, as so many marine organisms have done before us.

If the evolution of light production occurs fairly easily, can humans or other animals adapt to bioluminescent behavior? With the rare and inspiring glow of bioluminescence, possibilities are endless.





> "Picture a future that exists inside the waters that humans have barely explored."

Annual Review of Marine Science (2010). DOI: 10.1146/annurev-marine-120308-081028
Journal of Photochemistry and Photobiology B: Biology (2017). DOI: 10.1016/j.jphotobiol.2017.05.021

MOVE OVER MOTHMAN: CRYPTIC SPECIES AND TAXONOMY

BY B. PARAZIN, PHYSICS, 2023

DESIGN BY SOPHIE PATE, BEHAVIORAL NEUROSCIENCE, 2024

PHOTO BY UNSPLASH

Modern-day folklore is rich with tales of cryptid species: stories of undiscovered animals, lake monsters and strange creatures stalking the night. As fun as these stories are, they don't represent actual biology research, but in the same woods where people go hunting for bigfoot or the Mothman, one can find real-life cryptic species hiding in plain sight, disguised by our overreliance on morphology. A cryptic species is a species or group of species that have been mistakenly classified as a single species because of a lack of significant morphological differences. When we imagine two groups of organisms being different species, it's natural to imagine that they look different, but under the biological species concept, two groups of organisms are different species only if they would not or could not potentially interbreed in nature.

There are many evolutionary changes that can take place to prevent interbreeding that don't result in obvious morphological differences. Changes to non-visual mating signals are most common, so two different species evolve that have different mating pheromones or different mating calls to which other species won't respond. For this reason, biologists theorize that cryptic species are more common in environments where visual stimulus is less important, such as deep underwater or in underground caves.

A common misconception about cryptic species is that they represent recent speciation events and that there simply has not yet been enough time for the species to differentiate morphologically, and while some are indeed recently diverged, this is not always the case. There are many cryptic species with ancient speciation events. The bonefish genus *Albula* is one such cryptic species that is thought to have diverged at least 4 million years ago. Cryptic species likely arise when populations face strong selection pressure for current morphological traits during speciation, so in low-light environments, in extreme environmental conditions, and among organisms with highly specialized symbiotic relationships — where organisms display high degrees of morphological specialization — there are theorized to be an abundance of cryptic species.

However, some scientists push back against the use of the cryptic species designation, claiming it's inherently inexact. Cryptic species are only special because of humanity's reliance on visual clues to differentiate rather than any intrinsic qualities about the species themselves. Furthermore, in many cases, so-called cryptic species aren't as indistinguishable as the name would suggest, and there are often subtle morphological or chemical differences that can be used to tell two species apart. Biologists call these types of species "pseudocryptic" or leave them unlabeled depending on the subtlety of the morphological tells.

Studying and discovering cryptic species can seem like a triviality on the surface, but it has important implications for conservation, species containment, and species utilization. Because cryptic species often have subtle distinctions, they can occupy slightly different ecological niches or live in different habitats, making overall conservation much more important. It's common to discover that a single, wide-roaming species turns out to be a complex of many cryptic species with much smaller ranges, some of which are more at risk than others. Another example is with mosquitos in sub-Saharan Africa, which is made up of the *Anopheles gambiae* cryptic species complex, the primary vector of malaria. Studies have found that only certain species in this complex target humans, allowing for more targeted use of resources to better prevent the spread of malaria. One of the applications of biological species research is in utilizing biological control species, where people exploit species-specific interactions between crop pests or invasive species and an introduced species to control the invasive populations. Recent research has found that some of these control species are themselves cryptic species complexes, where only some of the species in the complex effectively control undesired species, such as in utilizing parasitic *Metarhizium anisopliae* fungi to control crop pests, where evidence suggests it forms a cryptic species complex where each species is specialized for a different insect host.

Taxonomy is one of the oldest sciences, yet after all this time, it is still imperfect. Our reliance on visual differences to differentiate species has sometimes led us to paint with too broad a brush when defining species and establishing taxonomic boundaries, but modern genetic and proteomic techniques are allowing us to discover a whole world of nuance in our previous distinctions. The more cryptic species we identify, the better our understanding of the world becomes and the more we can leverage that understanding to solve ecological problems.

Trends in Ecology & Evolution (2007). DOI: 10.1016/j.tree.2006.11.004
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YOUR BRAIN ON DEATH

BY GRACE LI, COMPUTER SCIENCE & BEHAVIORAL NEUROSCIENCE, 2025

Death has long been known as the event horizon of neuroscience. While it is still infeasible for neuroscientists to examine the experiences of dead brains, recent studies have provided much insight into the moments preceding death.

According to Daniel Condziella of Copenhagen University Hospital, brain death — currently, the most commonly accepted definition of legal death — is characterized by neurons swelling and flooding the brain with ions, razing the delicate electrical balance necessary for intercellular communication. While most people who begin the process of dying reach this endpoint, some are rescued from the brink of death. A unique phenomenon reported by roughly 20 percent of those resuscitated is the near-death experience (NDE). According to work by pioneering NDE researcher Pim van Lommel, an NDE can manifest in varying ways, but people commonly experience out-of-body sensations, life flashbacks, and positive emotions. It is no surprise, then, that NDEs are frequently associated with the notion of an afterlife. Some psychologists postulate that an NDE is the psyche's attempt to cope with the inherently traumatic sensation of almost dying.

PHOTOS BY SHUTTERSTOCK

A 2013 study by Jimo Borjigin and colleagues at the University of Michigan lends credence to a possible neurological source of NDEs. Borjigin implanted electrodes in the brains of nine rats, then delivered the rats lethal injections and recorded their electroencephalograms (EEG) as they died. Her team discovered that after the rats experienced cardiac arrest, their gamma oscillations — brain waves associated with focus, alertness, and REM sleep — flared to a state that Borjigin describes as "hyperconsciousness" before stopping entirely.

However, the wider neuroscientific community is hesitant to accept Borjigin's findings as a potential explanation for NDEs. "EEG tells us things about brain activity a bit like listening at traffic noise tells you what is going on in a city. It is certainly informative, but also an average of a lot of individual interactions," Anders Sandberg of Oxford University said in a review of the University of Michigan study to the Science Media Center. Other scientists criticized the small sample size as well as the logical leap needed to associate a concrete physical event, gamma oscillations, with subjective phenomena such as NDEs.

Findings such as those of Borjigin and her colleagues illuminate the potential for further exploration into NDEs. While neuroscientists predominantly concern themselves with the brains of the living, there is still much understanding to be gleaned from those approaching death.

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DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

GLITCHES IN STARS

BY SALMA ALAWI, COMPUTER SCIENCE & BEHAVIORAL NEUROSCIENCE, 2025

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Star-gazers are captivated by an astronomical phenomenon called a glitch. Glitches occur in neutron stars, which are remnants of a collapsed star and are the smallest stars in the universe. But don't underestimate them: they are extremely dense, with just a teaspoon of their matter weighing around a hundred million tons on Earth! When neutron stars form, they start rotating, caused by the compressing and shrinking of their matter. Over eons, the rotation of the stars starts to slow down. During the several million years these neutron stars spin, they are called pulsars, due to the pulsing appearance that occurs as the star spins.

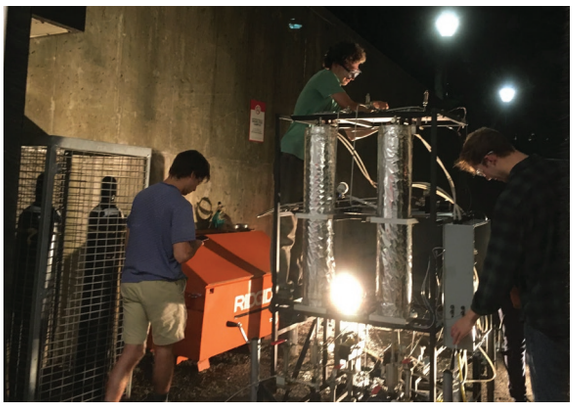
So, what do these stars have to do with glitches? A glitch is an increase in a neutron star's rotation frequency; essentially, the star starts spinning faster. However, scientists did not know why this occurred until 2016 when researchers at Monash University in Australia set out to discover the cause of these glitches. They studied the Vela Pulsar, a neutron star around 1,000 light-years away from Earth. The Vela Pulsar makes over 11 rotations every second and glitches about once every three years. Based on observations of the Vela Pulsar, the researchers proposed a hypothesis for why these glitches occur.

The conclusion was that glitches occur due to two different parts of the star interacting. Neutron stars have a layered structure, with a thin solid outer crust, a liquid inner layer, and an ultradense core. The inner layer is made of superfluid neutrons. Superfluidity is a strange state of matter where liquid flows with no friction against it and therefore loses no energy as it flows. This means that it can flow through tiny holes very easily, as there is no friction. When a glitch occurs, the superfluid inner layer moves outward, which hits the rigid outer crust. This causes the speed at which the star is spinning to increase. Very soon after, the star returns to its normal spin rate. The 2016 glitch in the Vela Pulsar lasted about 13 seconds.

There is still so much more to be learned about glitches in pulsars. A few seconds before the Vela Pulsar glitch, the star started spinning slower than normal before spinning faster. Scientists are unsure why this happened but are determined to find out why. Glitches are fascinating astronomical phenomena that can uncover secrets surrounding neutron stars and the behavior of superfluids.

Nature Astronomy (2019). DOI: 10.1038/s41550-019-0844-6

PHOTO BY NASA/JPL-CALTECH



PHOTOS COURTESY OF AERONU

A turbulent flight to success

A tale of Northeastern's very own aerospace club

BY NETHRA IYER, CHEMICAL ENGINEERING, 2024

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

It began with two members and one big dream: create a club that allows students to apply their engineering knowledge from class by building drones, planes, and rockets from scratch. Meet Northeastern's Aerospace Club, or AeroNU. With 200 members nearly a decade later, the Redshift team at AeroNU is quite literally reaching for the sky as they strive to complete the "Dollar Per Foot" challenge. Hosted by the nonprofit Friends of Amateur Rocketry, this is a challenge where students from different universities across the United States measure how high their rocket travels, with each foot earning one dollar. With the aim of reaching 20,000 feet within a couple of years, many AeroNU members are working diligently to complete the components of their rocket. As with any endeavor, there are plenty of challenges to overcome. One of the biggest challenges happened last spring when the engine fractured during manufacturing.

Down in the Mechanical and Industrial Engineering Capstone Lab, the AeroNU Propulsion team works tirelessly to design a liquid rocket engine full of small channels and features, grooves, overhangs, and screw holes. Because of the complex shape, according to Propulsion Lead Mark Galle, "this [engine is] pushing the boundaries in complexities." The engine's geometries are more complex than usual 3D printing allows. In addition, the engine is too large to print in one piece, so the team decides to print two halves and later join them. This was risky, but the resources were already available and the team decided it was worth a shot.

During the first print, the filament broke, causing the printer to stop and the bed to cool down. After the bed heated back up, microcracks appeared due to the thermal cycling. During the second print, the filament broke even more and the engine inevitably fell apart due to the internal microfractures.

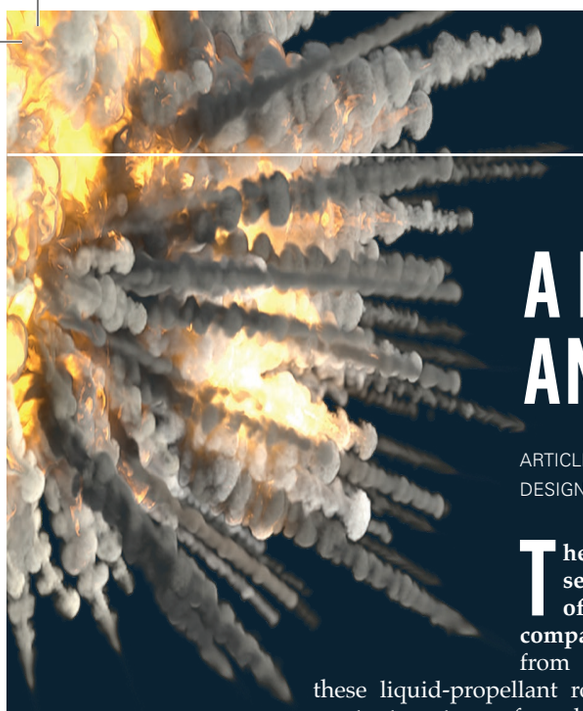
Hope was not lost for the team — they had prepared for issues like this. The team called for an emergency meeting to go over technical issues, redesigns, and next steps. They decided that even though it would be more expensive and require outside resources, the best course of action to create the engine would be direct metal laser sintering, a laser-based 3D printing method that fuses powder into layers. This method is more reliable because of its precision and accuracy.

With the new plan in mind, the team got back into the lab and made a few adjustments, including creating and reorienting the entire engine into a single piece. In the end, the engine came out wonderfully. Although the first engine may have cracked under stress, AeroNU most certainly did not. They too emerged stronger and wiser, as they learned quite a bit from this rough patch. One of the biggest lessons learned was the idea of cost.

"The [first] method that we were using was a great way to save a whole lot of money," Redshift Project Lead Isaac Kramer said. "However, it was far more complex and riskier than the way that we ended up doing it." When working on a liquid rocket engine — something that involves dangerous chemicals, explosive items, and hot gases — there comes a point where saving money is not as important as quality.

One of the best parts of AeroNU, according to its members, is the opportunity to step up and learn. Even those with experience, such as Propulsion Lead Sam Wohlever, are always curious to learn more.

"In all of our work, there is always a goal," Wohlever said. "Really, what we're striving for in this club is learning and improvement, both on an individual and club scale. We're able to take so many applicable skills away from this." It is this mindset, this passion, and this drive that allows a club like AeroNU to bounce back from setbacks. Members learn from their mistakes and understand that the path to success is not at all straight and perfect, but full of turns.



A NEW SPACE RACE IS UNDERWAY, AND IT'S BEEN EXPLOSIVE.

ARTICLE BY NOAH HAGGERTY, APPLIED PHYSICS, 2024
DESIGN BY EVELYN MILAVSKY, CELL & MOLECULAR BIOLOGY, 2025

The past ten years have seen an explosion of small-lift rocket companies. Ranging from 30 to 100 feet tall, these liquid-propellant rockets aim to launch up to two tons of payload — equivalent to the weight of a large car — into orbit. Instead of focusing on humans and large space telescopes, they're launching smaller scientific experiments, communication satellites, and college technology demonstrations. As they race to propel their rockets into space, they fight the tyranny of Earth's gravitational well and Murphy's law, stating that anything that can go wrong, will. Their mission is clear: beat the others to orbit, then radically drive down the cost of access to space.

To accomplish this, the companies have developed bold and innovative new ways to reach space, from 3D printing rocket engines to launching rockets from the wing of a commercial airliner. Reaching space has historically been difficult, with every success preceded by years of struggle, failure, and setback. This new age of rocketry is no exception.

Rocket Lab, launching from New Zealand, was the first to reach orbit. But, after 11 consecutive successful launches, they experienced their first anomaly in the summer of 2020. Partway through the second stage burn, the rocket wobbled, and their live video feed sputtered out. Shortly after the launch, the company announced the vehicle had been lost. They halted flights and initialized an investigation with the Federal Aviation Administration — a required step for any rocket company after a failure.

Four weeks later, Rocket Lab announced the failure was due to a faulty electrical connection. Its intermittent disconnections created a high resistance in the electrical components, causing them to heat up, liquefy, and destroy the circuit. This forced the second-stage engine to shut down.

Rocket Lab is not alone in its struggle to reach space. Virgin Orbit, a sister company of Virgin Airlines, experienced a failure on its first attempt to launch a rocket from the under-wing of a 747 airplane. When they released the rocket, its engine roared to life, accelerating the vehicle. Within seconds, the engine abruptly cut out. A propellant line had blown, and the mission was lost. However, Virgin Orbit fulfilled their namesake goal on their second attempt, making them the second of the bunch to achieve orbit.

Nonetheless, rocket engine issues, some dating as far back as rocketry itself, continue to plague the industry. In the late summer of 2021, two companies developing small-lift rockets experienced premature engine shutdowns on their first stages. The Alaska-based Astra's rocket slid sideways off the launch pad after an engine failed moments after liftoff, leaving the rocket without enough thrust to fight Earth's gravity. The other company, Firefly, flew higher, but their engine shut down 15 seconds into flight. The rocket pierced through the atmosphere, but once it reached supersonic speeds, it could no longer control itself without the missing thrust. It suddenly jerked sideways, completing a full somersault in the air before mission control detonated the rocket. Despite these setbacks, they are determined to reach orbit, with both companies are pushing forward towards their next launches.

Liquid rocket engines are notoriously complex beasts, known for their seemingly impossible-to-comprehend tangle of wires, sensors, pipes, pumps, and valves. These engines are designed to take in an oxidizer and a fuel, mix them in a chamber, and combust them. The scorching thousands-of-degrees Celsius reaction converts the propellants' chemical energy into kinetic energy and shoots the exhaust straight back to create thrust.

> "At such high combustion energies, there are dozens of ways the complex machinery of rocket engines can fail."

At such high energies, there are dozens of ways the complex machinery of rocket engines can fail. Incorrect oxidizer and fuel mixing ratios can cause the heat of combustion to increase and destroy the engine. Pressure differences and shock waves in and around the engine can create vibrations capable of shredding an engine in milliseconds. With each of these companies taking on the daunting task of developing their own engines, they assume the potential glitches that come with them — but also the potential benefits of customizing their engines for the needs of their vehicle.

Racing to orbit with new technology, these companies push each other to overcome their anomalies and fly past the reign of Murphy's Law. Tweeted messages of support between the companies' CEOs are a common sight. While the technologies and purposes differ, they share a dream of radical access to space. Where high school and college students can afford to send their experiments into orbit. Where a rocket launch is a common occurrence, and a failure is a rarity.

PHOTO BY WIKIMEDIA COMMONS

THE BIG RIP:
The universe's final stand

ARTICLE AND DESIGN BY DIVYA RAVIKUMAR, BIOENGINEERING, 2025

As infinite as our universe may seem, everything is destined to come to an end. The question physicists are asking themselves is exactly what that end will look like. With the continuous, accelerating expansion of the universe, one of those theoretical endings predicts the universe will eventually hit a limit where matter will deconstruct into its fundamental components. The force of gravity that is holding objects together will be overpowered, ripping apart the space-time fabric and everything in between, like a rubber band stretched too far. This outcome is better known as the Big Rip Theory.

The heart of this theory finds its origins in the concept of dark energy, a peculiar substance that constitutes 68 percent of the universe with the sole effect of expanding the universe at an accelerating rate. Dark energy is elusive because of its lack of presence. Physicists are aware it is inherently part of space, but its impact in expanding the universe is so slow and gradual that they have to look much closer to find evidence of its existence. Although there is still much research to be done on dark energy, it has been defined previously as a cosmological constant because the same density of dark energy exists in any given area of space — even as the universe expands under its pressure. Due to its consistency, no objects, such as galaxies, are disrupted; only the space in between objects would increase.

> "Molecules and atoms will split, reducing the universe to its barest forms until it finally cannot handle the pressure anymore, its expansion glitching as the fabric of space itself tears apart."

To quantify a substance's evolution over time in the universe, scientists talk about its equation-of-state, also known as w. The w of any cosmological constant is -1, and the same value was assigned to dark energy. However, physicist Robert Caldwell at Dartmouth College and his colleagues decided to explore the possibility of the value of w being less than -1, which is possible if the speed of energy were allowed to surpass the speed of light. As far as we know, nothing is as fast as light in our universe. However, if dark energy increases instead of staying constant, it would have to do so faster than the speed of light for it to rip apart the universe. In the calculations from their 2003 paper, Caldwell and his colleagues found that the data supported values of w less than -1 for dark energy. This new hypothetical version of dark energy was called "phantom dark energy," and unlike the previous definition of dark energy, it will not stay constant. Instead, it will grow stronger as the universe expands.

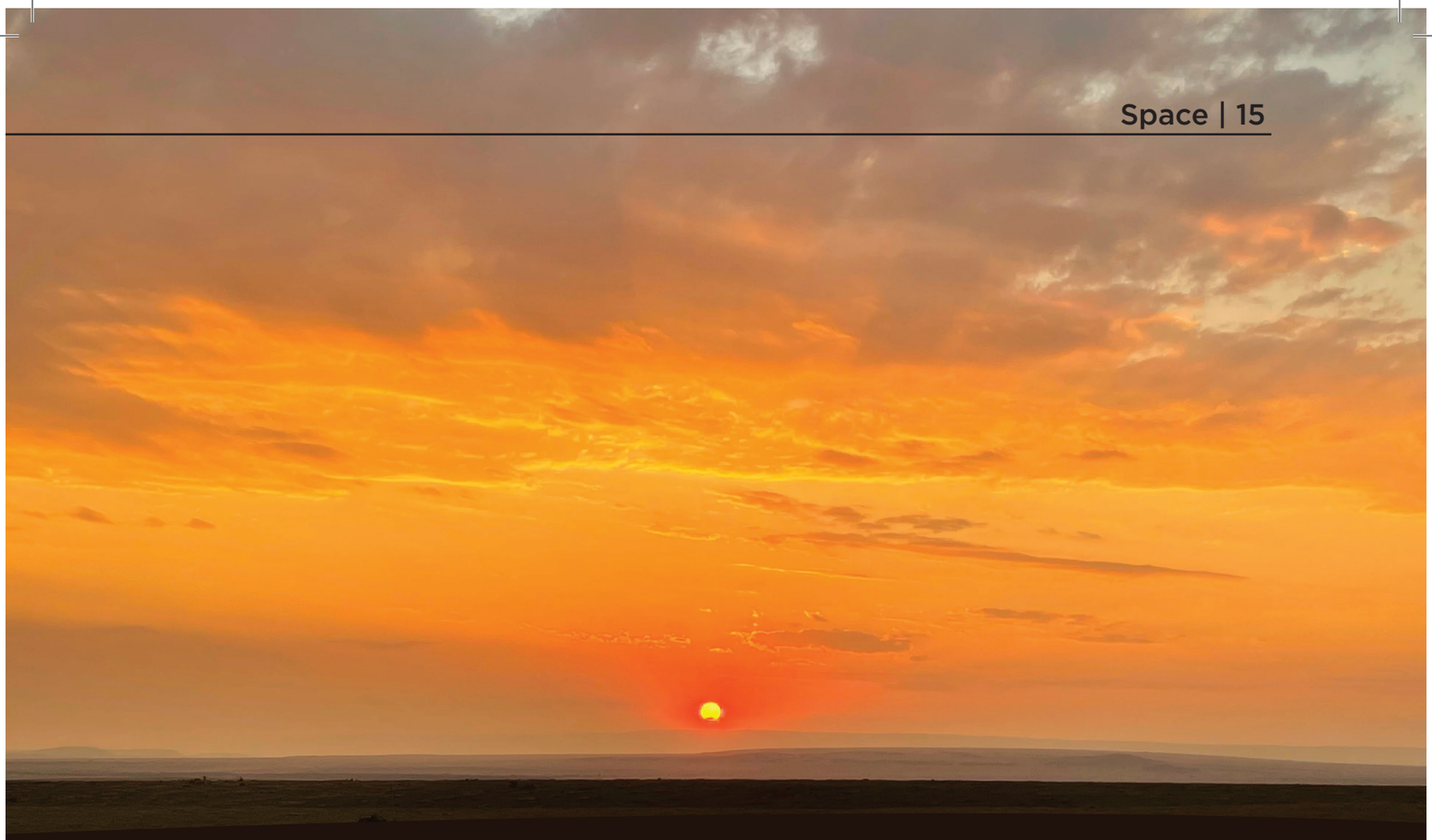
A second component plays a role in the Big Rip: the viscosity of the universe. Cosmological viscosity is a measurement of the universe's stickiness, or how resistant it is to expansion or contraction. In a more recent model developed in 2015 by Marcelo Disconzi of Vanderbilt University and his colleagues, they determined that the universe's viscosity is low enough for it to expand to an infinite size. Combined with the idea that dark energy will continue to increase in strength, there will come a point where dark energy will overtake the force of gravity.

And so, the Big Rip will unfold like this: the space between galaxies becomes infinitely lonelier as clusters begin to drift apart. Then, stars begin to drift away from their galaxies, and planets drift away from their stars, and moons from their planets. Celestial bodies will begin to explode as they pull themselves apart. Molecules and atoms will split, reducing the universe to its barest forms until it finally cannot handle the pressure anymore, the fabric of space glitching as it tears itself apart. Reality would then be reminiscent of the time before the Big Bang when everything constituted nothing.

Of course, this is all in due time — 22 billion years, in fact, according to Disconzi's hypothesis. Until then, we will continue to question exactly how our universe's end will begin.

Phys. Rev. (2003). DOI: 10.1103/PhysRevLett.91.071301
Phys. Rev. (2015). DOI: 10.1103/PhysRevD.91.043532

PHOTO BY SHUTTERSTOCK



THE SCIENCE BEHIND EARTH'S RED GLOW

BY RESHIKA SAI DEVARAJAN, HEALTH SCIENCE, 2025

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

When you think of glowing space entities, your mind might jump to the Sun, but what if I told you that our very own planet emits its own mysterious red light? You might be puzzled, and so were researchers in 2009 when a satellite detected shades of red light scattered throughout the planet. The root of this strange phenomenon lies in the chemistry of plants.

All plants undergo photosynthesis, a process in which light, carbon dioxide, and water are used to create chemical energy in the form of sugars. Chloroplasts reside within plant cells and are the sites of photosynthesis. During this process, chlorophylls, which are stacks of pigments packaged within chloroplasts, absorb photons, or particles of light energy. This light energy excites electrons within chlorophylls, raising their energy level. While most of these electrons are used in a series of photosynthetic reactions, a small portion drops back to their ground energy state. When this occurs, energy is emitted by the chlorophyll molecule in the form of red wavelengths of light.

This red-light fluorescence plays a key role in determining the health and abundance of plant life across the planet. By examining the global presence of red wavelengths from space, researchers can examine how biodiversity varies from region to region, as well as track the growth or reduction of plant life on Earth. In addition, chlorophyll fluorescence is also an indicator of the health and productivity of plants; when under stress, the efficiency of photosynthesis decreases, reflected in changes in red light emission. For example, when phytoplankton are in iron-deficient waters, their solar energy retention rate drops, leading to an increase in red-light emission. With the help of red-light detection, satellites in space can identify iron-deficient waters and iron-rich waters and determine which parts of the ocean are affected by human activities that result in these differences.

> "Red-light fluorescence undoubtedly plays a significant role in tracking the impacts of the destruction and degradation of plant life due to human activities."

Gauging plant conditions is critical for tracking the impacts of climate change. Red-light fluorescence undoubtedly plays a significant role in tracking the impacts of the destruction and degradation of plant life due to human activities. From the Amazon rainforest to the succulent on your desk, the red-light glow emanating from Earth's plant life is a useful and fascinating occurrence.

PHOTO BY RUTH BEKALU, BIOLOGY, 2025

Morally permissible but problematic

The complex duality of human challenge studies

BY MYA HEARD, HEALTH SCIENCE, 2024

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Physicians must abide by the well-known ethics of the Hippocratic Oath: first, do no harm. One particular method of research, however, seems wholly counterintuitive to a doctor's mission. Human challenge studies are a method of studying infectious diseases and their treatments by purposefully injecting a healthy participant with disease-causing microbes such as bacteria and viruses. At first read, this endeavor might seem immoral and outdated. However, challenge studies remain in use for their invaluable insights into the pathogenesis and vaccine development of infectious diseases including smallpox, typhoid, and malaria.

Today, challenge studies on vaccine efficacy closely observe a small cohort of participants, making them short, replicable, and cost effective. In contrast, phase II and III clinical trial tests involve testing a vaccine on a range of 100 to 100,000 participants, are often more expensive, and are less likely to lead to developments.

In addition to the benefits to society and efficient design, ethicists also argue for the morality of challenge studies using ethical theory. It is true that injecting a disease in human challenge studies entails some negative consequences for participants. Some might say this is grounds to deem human challenge studies morally impermissible. Yet, the morality of an act is determined not only by its consequences but also the intent behind it. A researcher conducting a human challenge study intends not to harm participants but to gain scientific knowledge for the sake of advancing disease treatment. Although the intentions don't change the consequences of a challenge study, one can argue the virtuous intentions of the researcher make this research method morally permissible.

> "One can argue the virtuous intentions of the researcher make this research method morally permissible."

When the world is threatened by a highly infectious, deadly virus, vaccine development becomes acutely important. In collaboration with the Imperial College London, hVIVO, a leading company in virology and human challenge study models, has been conducting a human challenge study using SARS-Cov-2 since June 2021. The goals of this trial are to continue developing vaccines and treatments for COVID-19 by inoculating participants with the Alpha variant and studying viral replication and the body's initial immune response.

Because participants in human challenge studies can bear significant risks with little direct benefit to them, there are strict ethical guidelines that must be followed. First, the hVIVO challenge study must be justified by sufficient social and scientific warrant. There are currently seven vaccines approved by the World Health Organization that are effective at reducing disease and transmission of SARS-Cov-2 — the number of available, effective vaccines against COVID-19 somewhat diminishes the warrant for the development of another vaccine. Second, participants must provide informed consent. This involves understanding the risks associated with the study and making an autonomous choice about participation. The hVIVO study has a good process for ensuring informed consent and is only seeking participants over 18 years of age, who can give direct consent.

Research studies may also not target participants who are from socioeconomic and racial or ethinic groups disproportionately burdened by the disease, as this goes against the ethical principle of justice. Black and Hispanic people experience a higher burden of prevalence, hospitalizations, and mortality from COVID-19 due to inequities in healthcare access and outcomes. Targeting these populations for a challenge study would essentially subject them to risks that, given the context of the pandemic and existing health inequities, are unjust. The hVIVO study is not targeted at marginalized communities and assures the medical treatment of all participants. Therefore, it does not pose blatant issues of justice.

Central to ethical research is an analysis of the benefits and risks. The demographic of participants in this study are healthy, competent 18-to-30-year-old individuals. Young people are generally less susceptible to serious disease from COVID-19, so inoculation of this age group is less risky. But it remains that contracting COVID-19 is inherently risky for any person because therapeutics to treat severe cases of COVID-19 are limited. Additionally, because the study is limited to young, healthy adults, the findings may not be generalizable to much of the greater population. This raises the difficult question of whether the benefits outweigh the risks. In the context of the COVID-19 pandemic, the potential benefits of a human challenge study are very high. Nonetheless, a look at how the hVIVO study stacks against ethical criteria reveals even the most beneficial research has strengths and weaknesses.

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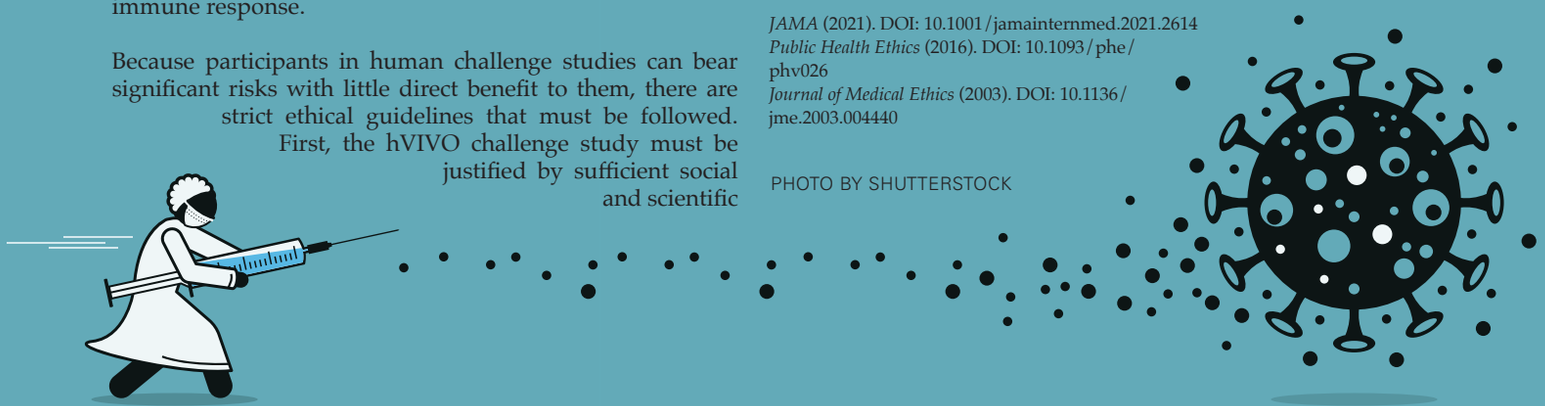
PHOTO BY SHUTTERSTOCK



ARE OUR BRAINS SELF-SABOTAGING?

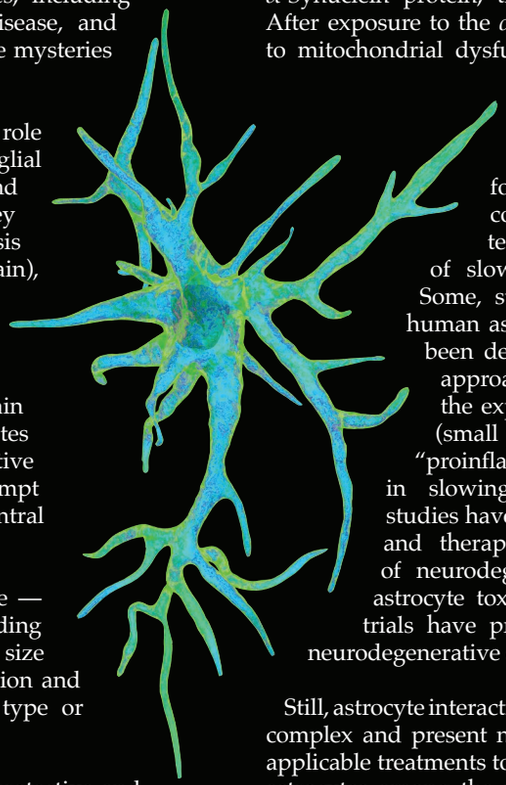
The role of astrocytes in neurodegenerative diseases

BY ELANA VON DER HEYDEN, BEHAVIORAL NEUROSCIENCE, 2024

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

Despite the modernity of medicine and the advancements mankind has made in understanding human physiology, there is perhaps no greater mystery than the driving force behind our every action, thought, and feeling: the human brain.

The physical structure of the brain is clear, but the origin of many of the existing neuronal pathologies is still uncertain. The brain — containing chemical gradients, neurotransmitters, and a confusing network of neural pathways carrying electric signals — is responsible for both astounding feats and immense suffering. Approximately 50 million Americans suffer from neurodegenerative diseases, including Alzheimer's Disease, Huntington's Disease, and Parkinson's Disease, to name a few. The mysteries of the human brain are partly to blame.



Even more curious is the perplexing role of *astrocytes*. Astrocytes are a type of glial cell that provide vital metabolic and structural support to neurons. They play an important role in neurogenesis (the growth of new synapses in the brain), maintain the homeostatic conditions that allow for a healthy brain, control water and ion composition outside of our neural cells, and maintain our blood-brain barrier. In the event of a brain injury or the threat of disease, astrocytes will enter a reactive state, known as reactive astrogliosis, in which the astrocytes attempt to repair any damage caused to the central nervous system (CNS).

Astrocytes are miraculous in this sense — they can have complex responses depending on the type of injury, can change their size and structure, and regulate the expression and function of genes depending on the type or severity of the damage.

So then, one might ask, how do such protective and helpful neural cells contribute to neurodegenerative diseases? The answer is that astrocytes are heterogeneous in nature: they are both helpful and incredibly detrimental to neuronal health. Although the role of astrocytes has been studied in nearly every neurodegenerative disease, focusing on their role in two of the most prominent neurodegenerative diseases provides a substantial understanding of the topic.

Alzheimer's is the most common form of dementia and results from plaque buildup that disrupts the brain's normal functions and interferes with cognition. Despite the advantages that astrocytes provide in the presence of this plaque — secreting enzymes to destroy it — astrocytes have been observed to develop a "proinflammatory phenotype" in which they no longer express genes involved in neuronal support as strongly, and thus contribute to neurodegeneration. These astrocytes, labeled A1 astrocytes (to distinguish them from helpful and normal functioning A2 astrocytes), are abundant in AD and secrete a neurotoxin that directly contributes to neuronal death. Furthermore, attempts at lowering the A1 astrocyte reactivity in mice had reduced the buildup of Aβ and restored neural deficits.

Affecting the motor system, Parkinson's disease is the second most common neurodegenerative disease and is caused by the dysfunction of multiple proteins within the brain. However, the main protein contributing to neurodegeneration, the α-Synuclein protein, transforms the function of astrocytes. After exposure to the α-Synuclein protein, A1 astrocytes lead to mitochondrial dysfunction and neuronal toxicity, rapidly killing neurons and other cells in the CNS, such as oligodendrocytes.

Suppressing A1 astrocytes has been the focus of many drug studies. In one study concerning ALS, numerous cell therapy techniques have been applied in hopes of slowing or stopping neurodegeneration. Some, such as the direct implant of healthy human astrocytes into the brain (of mice), have been demonstrated to be less effective. Other approaches, such as specifically targeting the expression of proinflammatory cytokines (small proteins produced by astrocytes in the "proinflammatory state") have proven effective in slowing pathology progression. Countless studies have been conducted on how certain drugs and therapies may help slow the progression of neurodegenerative diseases by inhibiting A1 astrocyte toxicity. The successes observed in mice trials have promoted new hope for the future of neurodegenerative disease treatment.

Still, astrocyte interactions and brain pathologies are extremely complex and present numerous challenges when developing applicable treatments to neurodegenerative diseases. Targeting astrocytes among the vast number of neural components is exceedingly difficult and demands continued research and attention. Despite the progression that has been made in understanding and targeting astrocytes, perhaps the biggest question about astrocytes is still unanswered. In the words of Stanford neurobiologist Shane Liddelow, "why [would] the injured and diseased CNS… produce a neurotoxic, reactive astrocyte?" In other words, why have our brains, when at their most vulnerable, created a habit of self-sabotage?

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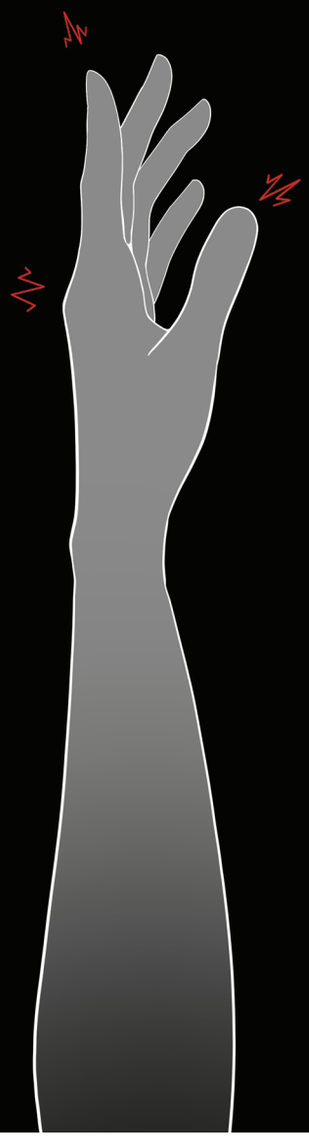
PHOTO BY SHUTTERSTOCK

HOW TO AMPUTATE A PHANTOM LIMB

BY JASON DENONCOURT, CHEMICAL ENGINEERING & BIOCHEMISTRY, 2023
DESIGN BY PARKER HITT, BIOLOGY, 2024



After an amputation, it is quite common that patients experience a vivid perception that their limb is still present. In fact, roughly 80 percent of patients report pain from the phantom limb. According to neurologist Dr. Vilayanur Ramachandran of the University of California, San Diego, within the first few weeks status-post an amputation, many patients report excruciating clenching spasms in the phantom hand, often accompanied by a feeling of fingernails digging into the palm. Ramachandran cites that it often takes patients several minutes or even hours to voluntarily unclench the phantom limb.

The cause of pain associated with phantom limb syndrome (PLS) is highly debated. Ramachandran speculates that the clenching sensation is a result of under-damped motor signals. In normal sensory-motor circuitry, the clenching motor signals sent from the premotor and motor cortex to the hand are damped by error feedback from proprioception, which is body awareness in the musculoskeletal system. However, in amputated limbs, this proprioception is incomplete and the signal amplification is felt as pain.

Another interesting phenomenon with PLS is memory-sensation association. For instance, Ramachandran notes that patients who frequently wore wedding bands or watches would maintain that sensation status-post amputation. Even conditions like arthritis flare-ups persist despite losing physical connection to the locations of pain.

Despite the widespread prevalence of PLS pain, current treatments are limited, rudimentary, and vary in effectiveness. Rather than addressing the primary cause of PLS, many treatments focus on symptom management, utilizing nonsteroidal anti-inflammatory drugs (NSAIDs) and opioids for systemic pain and antidepressants or anticonvulsants for nerve pain. Surprisingly, one of the most effective treatments is non-pharmacologic and attempts to control the phantom limb sensation: mirror therapy. In this method, a mirror is placed in a box to create an optical illusion. When a patient places their non-amputated hand inside the box, the reflection provides a visual representation of their phantom limb. This visual gives the patient greater control over their clenching spasms after weeks of practice, which Ramachandran has seen produce remarkable success. He noted that, although some patients saw increased sensation of the phantom limb, the required time to voluntarily unclench and relieve pain drastically decreased.

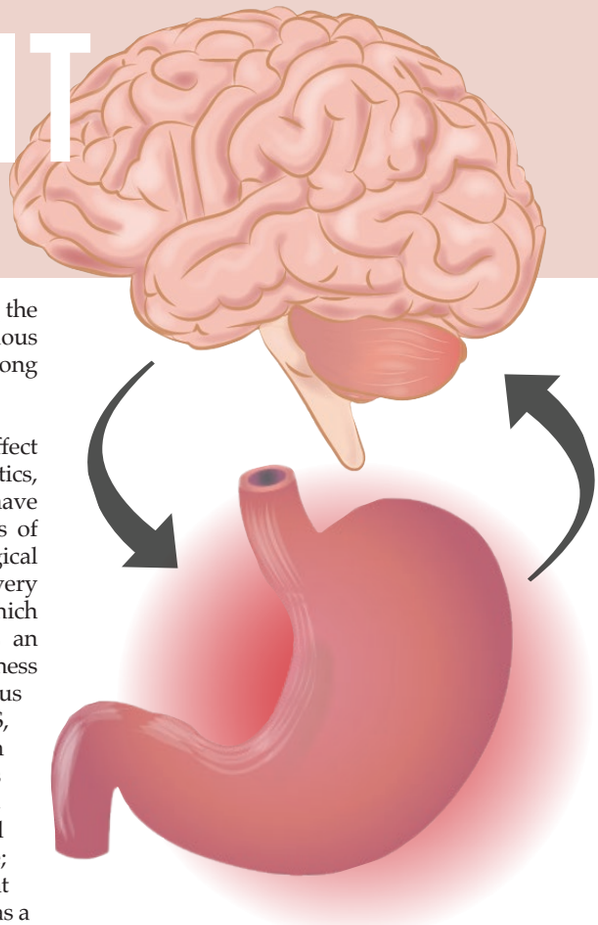
While little is still known about the pathophysiology of PLS and the associated pain, Ramachandran and other neurologists have grown interested in the topic as a way to explore the human somatosensory map and neuroplasticity.

Brain (1998). DOI: 10.1093/brain/121.9.1603

SHORT-CIRCUIT

A truly negative feedback loop

BY ANUSHKA BISWAS, CELL & MOLECULAR BIOLOGY, 2023



While it is generally agreed upon that the stomach bug is unpleasant, most of us find comfort in the knowledge that the queasiness will pass. Unfortunately, for 14-year-old Lillian Brown, her three-day-long virus came with lifelong reminders. On the third day of her illness, the pain in her stomach was so intense that she had to be hospitalized, and the ghost of the pain remained for the next year. As common as nausea is, she anticipated a quick trip to her pediatrician to find her answer. Specialists speculated that her issue might be a gluten allergy, irritable bowel syndrome, or perhaps a cry for attention, but all Lillian knew was that nothing made it better (and stressing about it surely made it worse). For over 400 days, Lillian woke up to constant nausea that caused her to miss out on school, extracurriculars, and her favorite foods with little reprieve. Lillian's body was seemingly in peak physical condition. Her situation reflected a textbook case of amplified musculoskeletal pain syndrome (AMPS) in a world with no book to reference. It took appointment after appointment, with countless unnecessary medical procedures, until the Center for AMPS at the Children's Hospital of Philadelphia (CHOP) could piece together what exactly went wrong.

An extremely painful medical condition, AMPS is a disorder in which pain is not registered by the nervous system in a typical fashion, leading to episodes of pain that may affect any part of the body. Typically, the pain circuit functions when damage occurring in the body sends a signal through a pain nerve to the spinal cord. This signal is transferred up to the brain, and the brain recognizes the signal as one that is painful. However, for patients with AMPS, this signal travels up to the brain as well as along the neurovascular (autonomic) nerves. These neurovascular nerves, also known as flight-or-fight nerves, then cause the blood vessels to constrict, limiting the amount of oxygen and blood flow available to the part of the body experiencing pain. Instead, lactic acid begins to build up, intensifying the pain response; this cycle is a continuous process, amplifying the pain for long periods of time.

There are many factors that affect amplified pain such as age, genetics, and hormones, but specialists have narrowed down three major causes of AMPS: injury, illness, and psychological stress. The onset of the pain can very much localize from a real event in which the body is suffering — such as an injury to the bone or muscle or an illness seen with inflammatory or infectious conditions. For children with AMPS, this pain lasts far longer than expected. Amplified pain comes in many forms including diffuse, localized, and intermittent as well as complex regional pain syndrome; associated episodes can be constant or sporadic, affecting areas as small as a singular limb or organ or as large as the whole body.

> "AMPS is a disorder in which pain is not registered by the nervous system in a typical fashion, leading to episodes of pain that may affect any part of the body."

With fewer than 10 facilities across the country offering treatment for children with juvenile AMPS, there is little research and awareness about the disorder. Luckily, not all hope is lost; the team at CHOP has devised a treatment program leading to 92 percent of patients becoming symptom-free and 88 percent of patients doing well after five years post therapy. Treatment involves a melting pot of techniques and approaches ranging from nonspecific physical exercise to desensitization therapy to stress management. Each child's experience is unique and tailored as they spend frequent sessions at the Center for AMPS clinic.

Before the clinic at CHOP, Zofran, a prescription anti-nausea medication, was Lillian's last hope — or so she thought. When an established gastroenterologist hypothesized that this condition would last the rest of her life, it seemed like the answer was nowhere to be found. It turns out, although her condition was localized to her stomach, the key to a healthier, happier life was nonspecific physical exercise. Doctor's orders included running 45 minutes daily, at times when her nausea was at its worst. Running mile after mile, day after day, coupled with anti-anxiety therapy, gave her mind the impression that her body was getting stronger — strong enough to fight off the virus that never left. Now six years later, Lillian's condition has yet to make a comeback.

Lillian is not alone in her pain, but she should not be alone in her recovery either. As gaining knowledge of her own body's strength helped her mind fight her illness, spreading awareness of AMPS can help thousands of kids worldwide.

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022
PHOTOS BY WIKIMEDIA

Vanishing twin syndrome and brain damage

The effects on the surviving twin

BY MADELINE SCHANEN, BIOLOGY & MATH, 2025

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Vanishing Twin Syndrome (VTS) is exactly as the name suggests: one of the two children in a set of twins vanishes. It usually occurs during the first trimester of the pregnancy, and can sometimes be mistaken for a miscarriage. The cause of the syndrome is unknown, but some possibilities have yet to be eliminated such as a small placenta or older age of the mother. Fortunately, the complications during the actual birth are limited or nonexistent at all. The earlier the twin vanishes, the less likely there are to be complications in the pregnancy or during birth.

There is still one baby remaining. What happens to the surviving twin? For the most part, the surviving twin is brought into the world without any harm done. However, there are some cases in which VTS could be the culprit to different outcomes for the twin.

A 2017 study published in *Fertility and Sterility* from the American Society for Reproductive Medicine showed that survivors of VTS had a higher risk for lower birth weight. This is likely because the death of one twin leads to a decreased blood supply for the other, which can harm the baby's size and development in some cases.

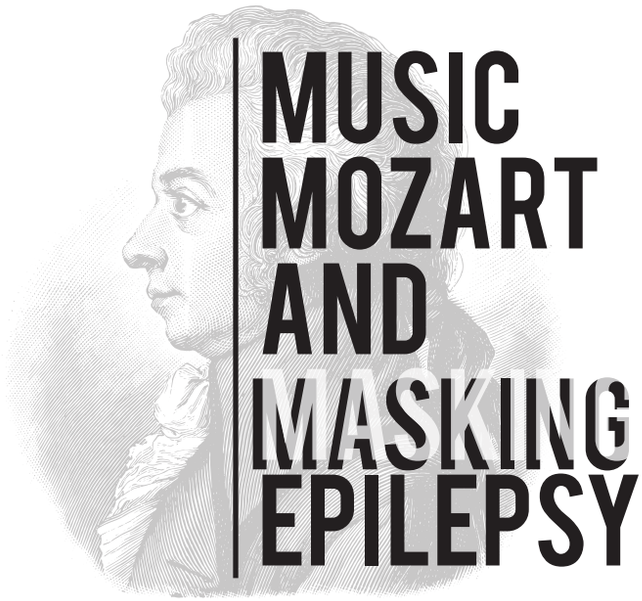
While lower birth weight is usually not an incredibly serious issue, one of the more concerning possible effects of VTS is brain damage. A study published in *Twin Research and Human Genetics* titled "Vanishing Twin: A Possible Cause of Cerebral Impairment," found some correlation between cerebral impairment and VTS. Causation, however, couldn't be established partly because of a small sample size, as generalizations cannot be made about an entire case by observing a small group. The data did show a noteworthy association between brain damage and VTS but claimed more research is needed.

So, that's exactly what happened. In 2016, a literature review published in Twin Research and Human Genetics titled "Fetal Brain Injury in Survivors of Twin Pregnancies Complicated by Demise of One Twin: A Review," discussed a specific condition concerning brain injury of the surviving twin not specific to VTS: Single Intrauterine Fetal Demise (sIUFD). sIUFD can cause a number of outcomes including early delivery, pulmonary hypoplasia (a condition where the lungs are small and underdeveloped), necrotizing enterocolitis (a condition where the intestine tissue is inflamed), long-term neurological complications, or neonatal death. While fairly rare, the risk according to the data is 7.5 percent for monochorionic twins — who share a placenta but not an amniotic sac — versus three percent for diamniotic twins — that each has their own placenta and amniotic sac. This is likely because the vanishing of one twin impacts the placenta that the surviving twin is also sharing. In VTS, the risk for this condition to a surviving twin is six percent, though existing data doesn't show whether or not being a VTS survivor and monochorionic puts the survivor at maximum risk. While quite rare, it is still notable and worth considering in further research. With a gap in the literature studying this topic, it's important to stress that there may be a lot of unknowns and unanswered questions.

One common question is how conditions like these can be treated or cured. A treatment called fetoscopic laser ablation was suggested by the 2016 study, but it is noted that there isn't much concrete evidence of a strong effect. In this treatment, a small camera locates damaged blood vessels and seals them with a laser while not being very invasive. Another option suggested in this study was to perform a "selective termination" to save the healthy twin if something like VTS is noticed early enough. This can prevent massive acute exsanguination, or blood loss, a cause of brain injuries in the surviving twin if the condition progresses for too long. VTS and its relationship to brain injuries is a very unexplored topic in the science of pregnancy and its potential conditions. Are there any other health conditions that persist in the long term due to things like sIUFD? Does head damage impact childhood development? These are just some of the questions that can point to future research. However, for now, it seems the mystery behind cases of brain damage in the surviving twin from VTS will remain.

Fertility and Sterility (2007). DOI: 10.1016/j.fertnstert.2007.06.048
Journal of Human Reproductive Sciences (2019). DOI: 10.4103/jhrs.JHRS_127_18
Twin Research and Human Genetics (2012). DOI: 10.1375/twin.10.1.202

PHOTO BY SHUTTERSTOCK



MUSIC MOZART AND MASKING EPILEPSY

BY NICHOLAS NG, BIOLOGY, 2024

Rhythm, melody, and harmony. Each genre of music has its unique combination of pitch, tempo, and texture. Each person's taste in music is extremely subjective, evoking different emotions and feelings. With so many moving parts, however, it is amazing how a single song can have universal effects on people. Often dubbed the "Mozart Effect," Mozart's Sonata for Two Pianos in D Major (K448) seems to have positive effects on all listeners alike.

In addition to temporarily increasing IQ, listening to K448 is shown to demonstrate therapeutic benefits with its ability to decrease epileptic activity. Epilepsy is a disorder characterized by sudden seizures. These seizures start as bursts of electric impulses in the brain that spread to neighboring areas, creating a cascade of abnormal electrical impulses. There are many causes of epileptic seizures, the majority initiated within specific seizure onset zones. For most epileptic patients, seizures are preventable and controllable with medication. However, 20 to 40 percent of epileptic patients have refractory (uncontrolled) epilepsy where medications are not effective. Instead, patients with refractory epilepsy often undergo invasive procedures such as epilepsy surgery, vagus nerve stimulation, and deep brain stimulation. K448 music therapy is a possible non-invasive, non-pharmacological treatment that has promising results for refractory epileptic patients. In a paper published in September 2021, a group of researchers led by Robert Quon set out to identify the components of K448 that give it such special therapeutic qualities.

In Quon's study, 16 people with refractory epilepsy were subject to Mozart's K448 for various lengths of time. The participants were neurosurgical patients that had electrodes previously implanted in their brains, allowing researchers to identify epileptic activity in each region of the brain in real-time. The researchers focused on interictal epileptiform discharges (IEDs), which are biomarkers for seizures. To study IEDs, the subjects were separated into two groups: one with 15-second listening intervals, and the other 120-second intervals. The intervals cycled between K448, a filtered version of K448 with boosted gamma frequencies, violet noise as a negative control, and Wagner's Lohengrin Prelude to Act One, another popular classical piece as a control for musical structure. These auditory stimuli were presented in random order, and each listening interval was followed by an interval of silence as a control.

Results showed that listening to K448 for short periods of time led to decreases in IEDs both in seizure onset zones and non-seizure onset zones alike. The effect was most strongly observed in the frontal regions of the brain, which are associated with working memory and emotional control. In line with that, the outcome was even stronger with longer listening periods; just 30 seconds of listening was required to elicit a significant IED decrease. Most interestingly, the results from K448 could not be replicated with any of the other auditory stimuli. In addition to those listed above, researchers also tested various classical pieces by Chopin and Liszt and songs from classical country, heavy metal, and rock and roll genres — all with no results.

> "The possibility of music as a non-invasive, non-pharmacological treatment for refractory epilepsy would strike a chord in the field of medicine."

By testing and comparing other genres, the researchers were able to pinpoint unique components of K448 that could lend to its therapeutic effects. In particular, they identified the musical structure of K448, including contrasting melodic themes with underlying harmonies. Based on the brain activation patterns observed, this musical structure may be responsible for causing positive emotional neural patterns in listeners and thus contributing to anti-epileptic effects. On the other hand, in Wagner's Prelude to Act 1 of Lohengrin, another classical piece, the absence of contrasting melodies leads to an absence of anti-epileptic effects. Another component of K448 adding to its ability to decrease epileptic activity is its frequency and sound signature. When researchers tested the filtered K448 with boosted gamma frequencies, the anti-epileptic effects of the original K448 were not present, suggesting that there is a unique frequency contributing to therapeutic effects.

By identifying specific components of K448 that set it apart from other classical, hip hop, and country music, Quon hopes to replicate K448's anti-epileptic effects with other stimuli using algorithms to search for similar music or combining beneficial components to create new music. Perhaps future studies will find an optimal listening length to elicit long-lasting therapeutic results. The possibility of music as a non-invasive, non-pharmacological treatment for refractory epilepsy would strike a chord in the field of medicine and may open the door to other nonconventional treatments for epilepsy patients.

Scientific Reports (2021). DOI: 10.1038/s41598-021-95922-7

PHOTO BY SHUTTERSTOCK

DESIGN BY YECHAN YANG, BEHAVIORAL NEUROSCIENCE, 2022

Oliver Sacks:
A decoder of neurological glitches

BY MAYA KRAUSE, ENVIRONMENTAL SCIENCE, 2022

DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

In the 1990s, the U.S. government heavily funded neuroscience research and sponsored numerous programs to educate members of Congress and the public about the wonders of the brain. But years before this "decade of the brain", the writings of a man named Oliver Sacks helped introduce the world to the complexities of neurology and cognition.

Dr. Oliver Sacks was born in 1933 in London, England to Samuel Sacks, a general practitioner, and Muriel Elsie Landau, one of the first female surgeons in England. Sacks' interest in science was fueled early, and by the age of 10, he had immersed himself in his basement chemistry lab. He eventually came to share his parents' passion for medicine, receiving his medical degree from Oxford University in 1958 and completing his neurology residency at UCLA before moving to New York City in 1965.

It was during the late 1960s, when he was working as a consulting neurologist for Beth Abraham Hospital in the Bronx, that Sacks encountered one of the first neurological "glitches" he would work with throughout his career. Sacks worked with around 80 patients who were catatonic survivors of the epidemic of "sleeping sickness", or encephalitis lethargica, which had swept the world from 1916 to 1927. Sacks experimented by giving the patients levodopa (L-DOPA), which at the time was hailed as a miracle drug to cure Parkinson's. The L-DOPA treatments miraculously awoke the catatonic patients, allowing them to emerge from their decades-long sleep. Some patients were able to stay awake and return to "normal" life while taking L-DOPA; others experienced uncontrollable side effects and were taken off the drug. Sacks chronicled his work with the "sleeping sickness" patients in his 1973 book Awakenings, which was eventually adapted into a feature film of the same name starring Robin Williams as Sacks.

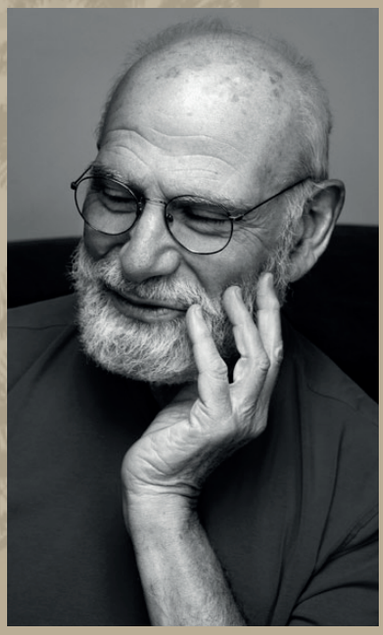
> " Dr. Sacks was criticized by some scientists for "put[ting] too much emphasis on the tales and not enough on the clinical."

Sacks worked with patients experiencing a variety of neurological conditions throughout his lengthy career, some of whom he discussed in his books. Sacks' 1985 bestseller The Man Who Mistook His Wife for a Hat is composed of 24 essays, each delving into the case of a different patient. The title comes from an essay on one of Sacks' patients who had visual agnosia, a condition that left the patient unable to recognize objects visually. For example, the patient could describe a rose as "a convoluted red form with a linear green attachment," but it was only after he was asked to smell the object that the patient could identify it. Along with the struggles of people with neurological conditions, Sacks also wrote about the talents of some of his patients, such as twin brothers who were severely mentally impaired and could not read, yet were able to spontaneously come up with 20-digit prime numbers. Sacks' essays presented his patients' humanity, seeking to help the reader understand the world in which his patients lived.

Sacks' work was extremely popular, with more than a million copies of his books in print in the United States. He was lauded for his work in academia as well, receiving honorary degrees as well as awards from numerous universities. However, Sacks' writings did not come without criticism. Sacks was criticized by some scientists for "put[ting] too much emphasis on the tales and not enough on the clinical", as put by Gregory Cowles of the New York Times. Additionally, some disability rights activists accused him of exploiting his patients for his literary career, to which Sacks responded "I would hope that a reading of what I write shows respect and appreciation, not any wish to expose or exhibit for the thrill, but it's a delicate business."

Sacks' writings showed the reader a glimpse into the lives of some of his patients, ranging from those experiencing rare neurological "glitches" to those with more common disorders such as Tourette's syndrome and autism. Through his illuminating writing style, Dr. Sacks was able to introduce the brain's quirks to a general audience and demystify those afflicted with neurological disorders.

BMJ (2007). DOI: 10.1136/bmj.39227.715370.59

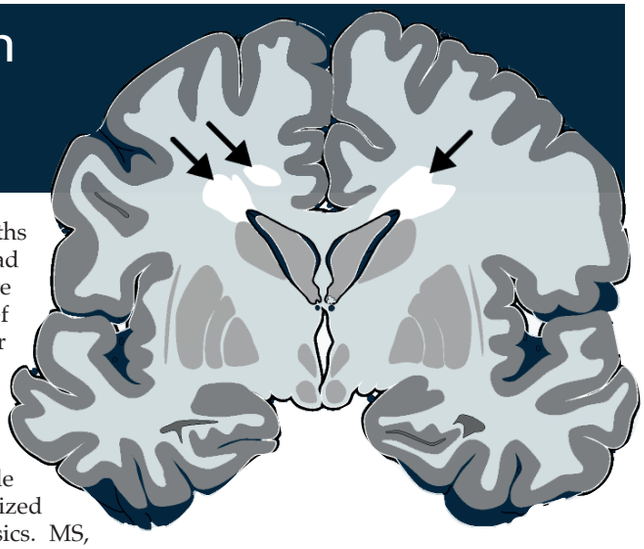


PHOTOS BY SHUTTERSTOCK AND QUOTEPARK

Shadowing during COVID-19:

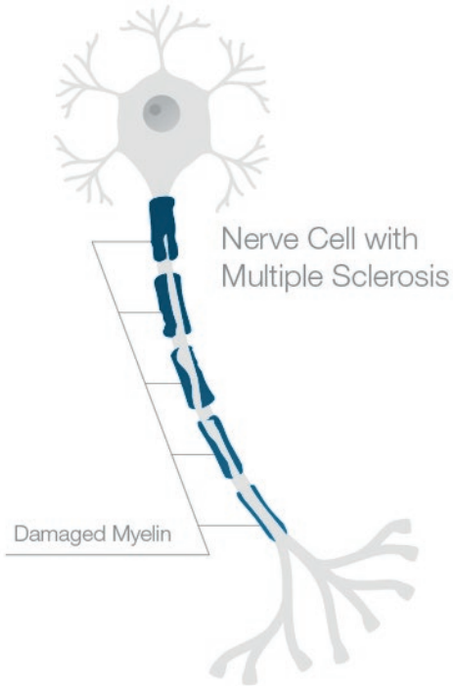
The fragile barrier between doctor and patient

BY LILY WEBER, BIOLOGY & ENGLISH, 2023



In a world where the COVID-19 pandemic is still continuing to fester, trying to find clinical experience is even tougher than usual. While these positions were already competitive prior to the pandemic, safety concerns over bringing even more bodies into clinical settings make them even more elusive than before. Yet, through all this, pre-med students still have the same rigorous standards to fulfill. While medical schools have issued vague reassurances over the obvious lack of shadowing and clinical opportunities during this "trying" time, pre-med students do as pre-med students always do: fret and worry over the state of their upcoming applications. I myself worried over the lack of shadowing experience I'd had.

That was how I found myself standing awkwardly outside the door of an Multiple sclerosis (MS) Clinic at my town's local hospital, awaiting the arrival of Dr. Christopher Langston, the neurologist I was slated to shadow for the next few months that summer. I had never met him before aside from our brief conversations over text, and I was far from an expert on MS, but as I feverishly Googled the abbreviation while waiting, I familiarized myself with the basics. MS, or multiple sclerosis, is a disease in which the immune system begins to attack the central nervous system as if it were a pathogenic invader. More specifically, the immune system goes after the myelin sheath that coats nerve fibers — think of it like the insulation that covers electrical wires. This nerve damage can cause a host of issues, many of which I would see firsthand within the next few months: things like numbness, weakness, tremors, difficulty walking, and impaired vision. Prior to my shadowing experience, MS was like this specter in the back of my mind. I'd always heard about it and it sounded scary, but I'd never seen it up close and I didn't exactly know what it was. Whether I realized it at the time or not, I would soon become intimately acquainted with its pathogenesis.



On a typical day of shadowing, my routine started early. I would usually arrive at the hospital ahead of the clinic's 8 a.m. opening time. More often than not I'd get there before Dr. Langston, so I would sit in the waiting area until his arrival. Once he arrived, he would take me through a rundown of the day's appointments, and then I would observe as he met with patients. After the first few appointments, if he had a break in the schedule, we would walk to the cafeteria to get coffee. As we went, I'd pepper him with questions about medical school, residency, and MS. Since I was simultaneously taking biochemistry over the summer, he'd often inquire about how my studying was going. Next we would return to the office and continue seeing patients, me furiously taking notes all the while. At a certain point, I would have to gracefully duck out of the appointment we were in and run home in time to catch my biochemistry lecture. It was a hectic routine, but starting my day off by spending time with a doctor actually did wonders for my motivation by the time I logged onto my Zoom class. It reminded me of what I'm working toward.

I also learned a lot about the problems that have arisen when COVID-19 intersects with MS. MS patients are considered immunocompromised, as the medications that slow symptom progression effectively suppress the immune system. As such, contracting even a mild infection or virus can be disastrous. Among a slew of questions about symptoms, MRIs, and medication, Dr. Langtson regularly inquired about whether his patients had received the vaccine yet. Many of them had, but unfortunately for MS patients, getting protection against COVID is not as simple as getting the vaccine. Because of their immunosuppressive medications, their bodies do not always produce the antibodies after receiving the injection.

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PHOTOS BY WIKIMEDIA
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

On an overcast day, the John Hancock Tower is free of reflections and impeding colors. By shooting at an angle and only including uniform windows, an illusion of infinity is created for viewers.

PHOTO BY MIMI PEREZ, ENVIRONMENTAL STUDIES, 2025

Computer Viruses:

Can our technology social distance?

BY KAELEN ENCARNACION, BIOLOGY & ENGLISH, 2022

DESIGN BY JAY KRITHIVAS, ECOLOGY & EVOLUTIONARY BIOLOGY, 2025

"**I'm the creeper**; catch me if you can!" This simple — albeit slightly disturbing — message was the only output of what is considered to be the world's first computer virus. Created by Bob Thomas at BBN Technologies in 1971, the "Creeper" program was an experiment to test if it was possible for a computer program to self-replicate and move across computers. Since it didn't cause any damage to data, Creeper wasn't considered malicious software. The "Reaper" program was even created soon after to delete it. However, the true disastrous nature of computer viruses was yet to be discovered.

"Andy; I'm just doing my job, nothing personal, sorry." What seemed like an odd spam email in 2004 turned out to be the worst computer virus outbreak in history: MyDoom. Technically considered a "worm," which is a malicious computer virus that can self-replicate and propagate independently once it breaches a system, MyDoom spread by taking email addresses from infected computers and sending copies of itself to those addresses. It would then expose these computers to DoS (denial of service) attacks, designed to shut down a target website or server. Known as the fastest-spreading email worm ever, MyDoom caused estimated damage of $38 billion in 2004 which, adjusting for inflation, equates to approximately $52 billion today. The creator of MyDoom remains uncaught to this day.

Since its conception in the 1970s, the landscape of computer viruses has varied from small, harmless programs like Creeper to catastrophic worms like MyDoom. The reasons for creating computer viruses are likewise diverse. Some, like Robert Tappan Morris, a Cornell graduate student who created the Morris worm in 1988, create them simply because they want to know if they can. Others, known as cybercriminals, do it for money. They resort to any means possible — spyware, ransomware, Trojans (similar to clickbait articles) — to steal personal and financial information from a target company or individual. A cybercrime is committed approximately every 30 seconds worldwide, according to a study by the Clark School, with the biggest targets being small organizations at a rate of one malicious email out of every 323.

Besides their shared penchant for destruction, computer viruses are named after biological viruses because they have similar mechanisms. In biology, a virus has no way to replicate by itself. It injects its DNA into a host cell and uses the cell's natural machinery to reproduce. With some viruses, the host cell fills up with viral particles until it bursts, causing the virus to spread to other cells. With other viruses, the host cell stays alive while viral particles "bud" off and spread. So like biological viruses, computer viruses require a host, such as a program or an email, to launch and infect other computers.

Many companies have come up with ways to combat harmful computer viruses that are similar to how the body might defend itself from biological viruses. Using the concept of innate immunity, antivirus software works by scanning incoming files that pass through a network and running them against an extensive database of known malware. The software then detects, flags, and removes any potential viruses before they can cause damage to the computer. With an extreme outbreak like MyDoom, companies might resort to shutting all their computers down so the virus can no longer spread, similar to human quarantines and lockdowns.

Given these biological parallels, would it be possible to create a computer virus "vaccine" based on adaptive immunity? Short answer: kind of. Theoretically, it might be possible to create a relatively benign line of code to "prime" the computer and teach it how to respond to foreign "antigens" in case of future exposures. While circulating on the Internet, they could block common entry points for viruses or even repair any viral damage automatically. However, these vaccines still come with potential drawbacks: even a good virus program would use up valuable disk space, memory, and CPU time which would slow data transmission, and malicious viruses can be disguised as beneficial ones to evade detection.

As with any viral pandemic, we must take the necessary precautions to keep ourselves safe. Install antivirus software, watch out for email phishing scams, and tell your friends and family about smart internet practices. Look out for any signs of infection on your computer: repeated error messages, battery drains too quickly, unexpected shutdowns, etc. In an age where the word "virus" is now a household name, educating yourself and knowing the facts is the best way to stay safe.

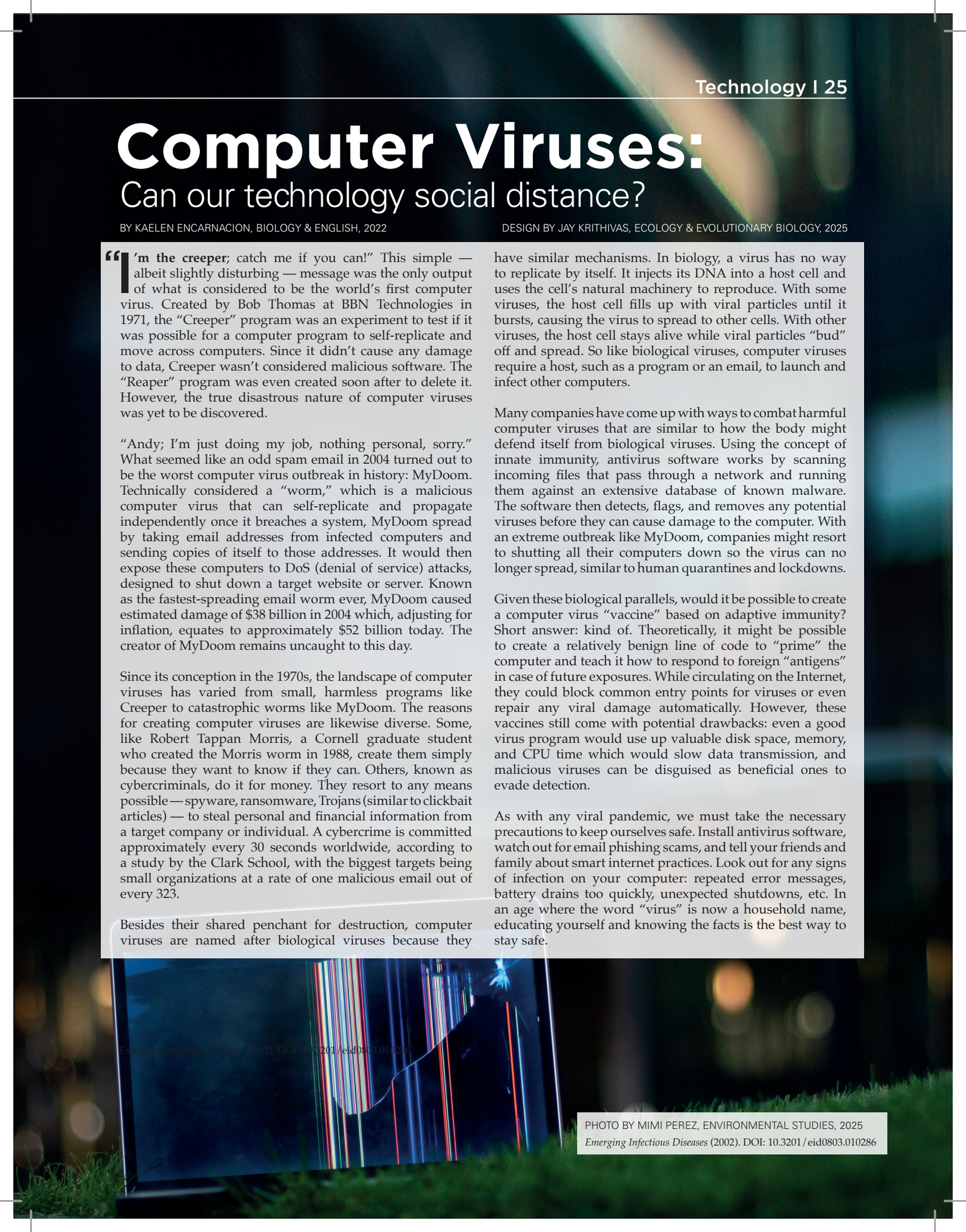

PHOTO BY MIMI PEREZ, ENVIRONMENTAL STUDIES, 2025

Emerging Infectious Diseases (2002). DOI: 10.3201/eid0803.010286

Thinking computers? Not yet

BY PABLO KVITCA, COMPUTER SCIENCE, 2022
DESIGN BY LILLIE HOFFART. ENVIRONMENTAL SCIENCE, 2022

For a few years now, computers have been getting better at generating text (and images). Since OpenAI (an Elon Musk–funded private artificial intelligence research lab) published their new GPT-3 (Generative Pre-trained Transformer-3) language model last year, hype around its capabilities has been growing, and many similar and even more powerful models have been created. Language models like this one are computer programs that can generate human-sounding text with very little input. The current state-of-the-art programs (like GPT-3) can create extremely detailed and on-topic outputs.

Many of these models are available on a playground for journalists and researchers to try out. Most articles on this topic will have a quote or two that were created by this technology, and more often than not, the journalist will first say that it was said by a real person, only to later reveal their lie. This is usually followed by equal parts praise and skepticism at the computer and, sometimes, fear. This reaction makes sense; computer language models are now extremely good at mimicking human language. They can make full paragraphs and "answer" questions from human text input.

> "[Computer] language models have several disadvantages, including encoding and spreading biases from their data and their expensive computing cost (and environmental impact) needed to create them."

As highlighted by the now-famous "Stochastic Parrots" paper by Dr. Emily M. Bender and Dr. Timnit Gebru, these language models have several disadvantages, including encoding and spreading biases from their data and their expensive computing cost (and environmental impact) needed to create them. Each of these weaknesses poses some danger, the need for fair AI and environmentally conscious AI is being addressed in research communities such as the ACM Conference on Fairness, Accountability, and Transparency and the work by Roy Schwartz and colleagues on Green AI. However, the hype around these language models has pushed them to be used in products like GitHub's Copilot, a software coding assistant, and many community-created demos on applying the technology to all kinds of new problems.

These language models work by going through millions of text data (mostly English) and codifying the words, forms, frequencies, and usage into numbers and probabilities, but they don't codify their meanings. In their most basic form, these models simply predict the next word in a sentence; then, they chain together several predictions to generate arbitrarily long text. When we read this text, we imbue the text with coherence and intention, but this is merely an illusion.

Some people argue that we just need to insert more parameters and data into the models, and eventually they will learn enough to be used as General AI, computer programs that can solve any problem with minimal reconfiguration or reprogramming. It might be possible to use this to create a system that will pass the Turing Test, which tests whether people can distinguish between a computer and a human actor. However, a computer that seems to be human does not necessarily think on its own. If fed with enough data, it might just repeat something it has already seen that was said by an actual human (in the AI field this is known as overfitting).

In many applications, the use of computer-generated text is not clearly displayed to the user, and they might think a human is behind the conversation. The text might explain things and show logical thinking but purely by chance. The output of the models is unpredictable; it might change topics randomly, or it might lead a conversation towards topics it is biased towards, possibly causing harm (such as furthering biases and discrimination against protected groups).

General AI might be on the horizon, since some breakthroughs on more complex designs for language models seem to give the computer the ability to make decisions. Yet, what we currently have is a bad approximation of a kid repeating words they heard on TV without understanding their meaning: The computer's output is synthesized text that we, as humans, can interpret and give meaning to, but the computer doesn't understand what it is saying or the meaning behind any of the words and sentences it parrots out.

Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency (2021). DOI: 10.1145/3442188.3445922
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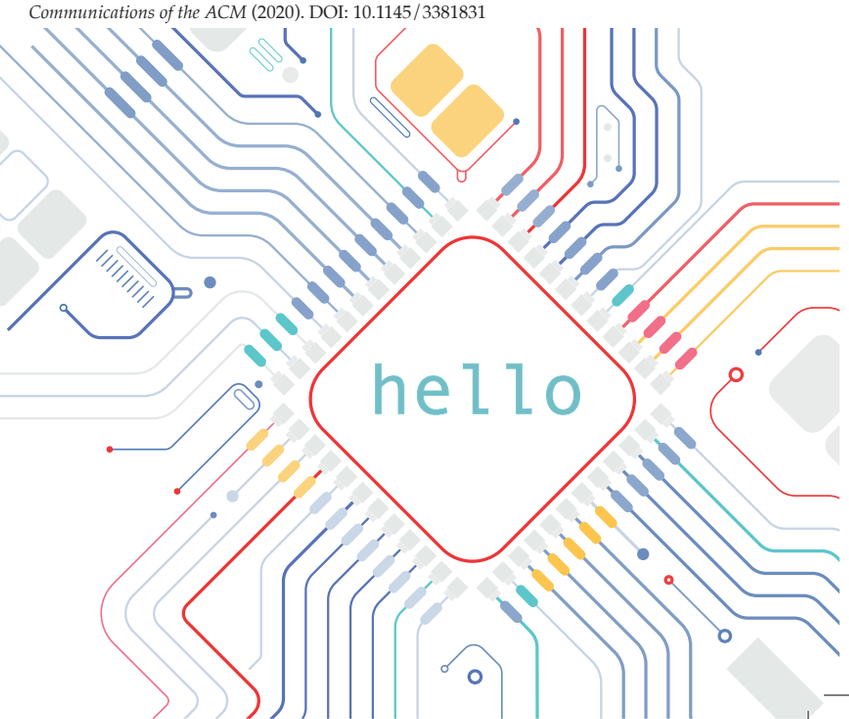

PHOTOS BY SHUTTERSTOCK

On computers, aesthetics, and the end of the world — A.K.A., Y2K

BY DHRITI AIYLAM, BEHAVIORAL NEUROSCIENCE & ENGLISH, 2024

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

The phrase "Y2K," instantly conjures up images of baby tees, Britney Spears, Bratz Dolls, double denim, and MySpace. The Y2K aesthetic has massively surged recently thanks to social media and celebrities' fashion choices — a manifestation of the nostalgia associated with the late 90s and early 2000s. But what does "Y2K" really mean, and why is it that this buzzword is far from nostalgic for a lot of people?

Y2K, short for "Year 2000" and also known as the Millenium Bug, was actually a problem in the way information was stored in computers prior to 2000. To provide some context, during the 1960s, dates were formatted so that years were only two digits. For example, October 6, 1960 would be formatted 100660, with the assumption that the 60 meant 1960. As computers were in their infancy, this was the best way to save memory space and speed up processing; it was assumed that as technology progressed, this system would change. Except the system worked so well that it never *did* change. Computer scientist Robert Bemer tried to bring up this issue as early as 1971, but it was always considered a problem for later.

As the millennium drew to a close, though, people began to take notice because on January 1, 2000, computers would think the date was actually January 1, 1900. Programs everywhere would malfunction, including in industries like banking and government. It wasn't only mainframe computers in danger — embedded systems (microprocessors) that function within larger systems in sectors like hospitals, elevator factories, electrical generation plants, and even nuclear reactors were liable to be impacted by the Y2K bug, causing massive-scale malfunctions. This understandably caused panic; many people likened the Y2K bug to the apocalypse and began stockpiling canned goods, withdrawing cash in case ATMs no longer worked, and buying backup generators and guns. Y2K even inspired a host of disaster-themed songs, novels, movies, and a cookbook!

> "Programs everywhere would malfunction, including in industries like banking and government."

The actual fix wasn't too difficult but would be rather time consuming. Someone familiar with the COBOL programming language would have to sift through code line by line and look for date logic, changing the two-digit year to the four-digit year. The worry was that there would not be enough time to make these fixes and that it would be extremely costly to do so (which was the case — the United States ended up spending around 100 billion dollars).

Luckily, this crisis was taken seriously. Congress members, both Democrat and Republican, devoted much effort to making sure that utilities, financial, and healthcare sectors would be ready. On July 14, 1998, President Clinton passed Good Samaritan legislation to encourage collaboration between government and industry, ensuring that businesses sharing critical information about Y2K would be protected from liability if their information turned out to be incorrect, and pledged to help other nations with a 12 million dollar grant. Clinton even appointed a "Y2K czar," John Koskinen, to oversee operations during the crisis. Thanks to the hard work of programmers and IT professionals, the looming calamity was avoided.

Because of the uneventfulness of January 1, 2000, though, many people believed the threat of Y2K was greatly exaggerated into mass hysteria or was even a hoax. People speculated it was created for programmers to make money, and many business owners complained about what they had to spend to prepare for it. However, what they didn't know was that there were a lot of little Y2K-related mishaps, just not as noticeable as the major event people were anticipating. For example, a nuclear energy facility in Japan suffered some malfunctions of radiation equipment, but this was not a major problem thanks to backup facilities. Unfortunately, though, much of the grueling work done did not get recognized. As Koskinen said, "If it works well, nobody cares much." This could be an issue in future crises — because Y2K was so ridiculed, when another similar problem arises, it's possible that no one will take it seriously.

Why should we care about Y2K since it happened over 20 years ago? Y2K gave companies a chance to update all of their hardware and software as they questioned how they interact with data, and making these changes equipped them to become the more efficient and productive workplaces of today. Additionally, Y2K boosted the practice of hiring overseas workers, especially from India for their knowledge of older machines and programming languages. Infrastructure and people in today's business are what they are all thanks to the Y2K bug.

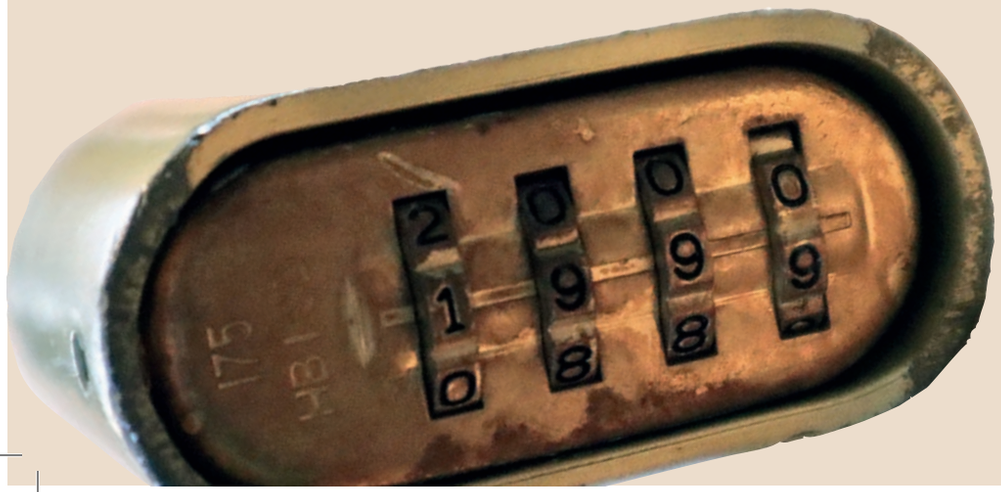

PHOTO BY HARRISON NG, BIOLOGY, 2023

IOS 14.8: NOT YOUR AVERAGE APPLE UPDATE

BY RAISA BHUIYAN, COMPUTER SCIENCE & MATHEMATICS, 2025

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Did you get an alert three weeks ago saying you needed to update your iPhone? Well then stop what you're doing, check your settings, and update your phone right now. This update may be the most important one to date; the iOS 14.8 update is designed to protect your Apple devices from being hacked without even needing to enter a link.

This vulnerability was discovered by the University of Toronto's Citizen Lab in March 2021, according to the lab's website, when the lab examined a Saudi activist's phone infected with Pegasus spyware. Pegasus spyware is software that can be used to hack into a person's device and was developed by an Israeli company NSO. NSO has licensed this software to many international governments. When examining the phone, researchers discovered an exploit nicknamed FORCEDENTRY that attacks Apple's ability to produce PDFs. What makes this exploit unique is that it can be installed on your Apple product in mere seconds without using a link — hence the name "zero-click."

Once FORCEDENTRY enters your device, it can perform a wide range of actions — from using your camera to sending your messages to foreign parties. "This spyware can do everything an iPhone user can do on their device and more," John Scott-Railton, a senior researcher at Citizen Lab, said to *The New York Times*.

Apple has fought back by releasing iOS 14.8. This update fixes a variety of bugs in Apple's software, such as how Apple handles its memory or how Apple properly checks any variables that are input into its system to avoid an overflow of information. Without the update, if your device processes an "infected" pdf, it executes code that allows the hacker into your device. Another way a hacker could enter your phone is if the user clicks on a bugged website.

Although Ivan Krstić, Head of Security Engineering and Architecture for Apple, said the attack won't affect the majority of its users, this update is highly recommended as a safety precaution.

THE GREAT UNCONFORMITY: THE BILLION-YEAR GAP IN EARTH'S GEOLOGICAL HISTORY

BY FELIPE PADILLA, COMPUTER SCIENCE & ECONOMICS, 2025

DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

In many ways, planet Earth is very much like a toxic relationship. It is beautiful in some moments, has destructive episodes via natural disasters, and is very secretive. Geologists have long been pondering a particular secret that the Earth has kept from us known as the Great Unconformity— a billion years missing from geological records. Are we truly in the dark, or is there some useful information hidden under the rocky surface?

The Utah Geological Survey describes an unconformity as "a type of geologic contact — a boundary between rocks — caused by a period of erosion or a pause in sediment accumulation." In other words, imagine placing a layer of macaroni and cheese in a Tupperware container, waiting a whole year, and putting a new layer of macaroni on top of it. If the food was rock, the line that splits the new and aged layers of macaroni and cheese is called an unconformity. The key factor in an unconformity is age, in which the two layers vary extremely. In the case of the Great Unconformity, estimated to represent the rock record from Cambrian times (550 million years ago) and the pre-Cambrian (anything earlier), the difference in age between the two l ayers is thought to be more than a billion years.

Many theories involving the past are discovered through the study of fossils and carbon-dating once organic material. However, archaeologists have debated about the exact period the Great Unconformity represents. It is also unknown how it was removed, though it has probably gone either through erosion or another sediment movement. Conveniently, the Great Unconformity is seen most vividly throughout the Great Canyon. Studies from *PNAS* theorize that glaciation around the planet could have occurred during the Neoproterozoic era, as far as 720 million years ago. This would have led to massive amounts of erosion — a potential cause of this missing sediment layer. Allan Treiman, a member of the Lunar and Planetary Institute, explained that the Great Unconformity "represents a long span of time from 250 to 1200 million years in the Grand Canyon." While we still don't know exactly how much time the Great Unconformity represents, this gap in our Earth's history is much too big to ignore.

While it is worrisome that so much history is hidden from us, it is also humbling. The Great Unconformity is a reminder that the impact we make on the world is beyond the tangible, as all material shall erode and fade away in the sands of time. The time we have here should be cherished and used to its full extent, as the artifacts and societies we have built will eventually crumble. This proves that nothing is truly set in stone and, as the Great Unconformity reminds us, it is better to enjoy and focus on the present rather than stay in the past.

PNAS (2019). DOI: 10.1073/pnas.1804350116

PHOTOS BY SHUTTERSTOCK

THE FUTURE IN TERMS OF URBAN MICROCLIMATES

BY ANNA DUCROISET, BIOCHEMISTRY, 2025

DESIGN BY KAI GRAVEL-PUCILLO, PSYCHOLOGY, 2022

According to the UN, approximately half of the world's population lives in urban areas, with this number projected to grow. It is more essential now than ever to mitigate the toll urban areas have on local climates and environments. Urban areas tend to be significantly hotter than their surroundings due to heat trapping and heat production. This is a result of a variety of flaws inherent to the design of many cities: too little green space, buildings made from non-ideal materials, and increased air pollution and heat production from human activity. As a result of increased heat production and trapping prevalent in cities, urban heat islands form.

A heat island is defined as "an area, volume, or region in which the temperature is higher than that of its surroundings" according to the *Encyclopedia of Energy*. The heat difference in heat islands is measured among fixed points (for example, the temperature in a rural district outside of a city compared to the temperature at the heart of an urban center). Heat islands are partially a result of the combustion of energy that is inherent to a city: cars, air conditioners, trucks, and the use of machinery, to name a few. To accommodate this added heat, those within urban centers are forced to use more of the machinery such as air conditioners that caused this heat imbalance in the first place.

The use and conversion of energy common in urban areas leads to an increase in air pollutants emitted, which enhances local greenhouse effects. The greenhouse effect is the result of atmospheric gases that essentially act like a blanket around Earth. These gases help to trap heat within the atmosphere and prevent harmful sun rays from reaching Earth. However, issues can arise when local greenhouse gases are abundant in human-occupied areas. For example, in areas with high temperatures, there tends to be an increase in the amount of ozone produced. Atmospheric ozone is generally not harmful to healthy lungs; however, the ozone that results from smog production and pollutants is seriously detrimental to human health. Some effects of breathing in this "bad" ozone are shortened life span, increased risk of lung disease, and worsened or even fatal asthmatic conditions. Those who live within urban microclimates are at a significantly greater risk for developing these conditions because they are more exposed to the pollutants.

PHOTO BY SHUTTERSTOCK

Ozone inhalation is just one example of the plethora of health issues that can result from poor urban planning and the increased urbanization and development of microclimate conditions. The imminent environmental and human health impacts of urban microclimates have led to a desire for many industries to seek improvements for the design of these areas.

A 2011 article from researchers at the University of Athens describes and critiques four potential mitigation strategies for urban microclimate areas. One highlighted method of regulating urban heat islands is to use building materials that do not have a high absorbency, referred to as "cool materials." These cooling materials greatly reduce the temperature of the buildings and help to reduce the demand for electricity that is usually necessary when buildings are made with heat-trapping materials.

Another method of reducing the heat island effect is increasing the green spaces present in urban areas. Plants are natural canopies, which leads to a decrease in the temperature on the ground and prevents heat from being transferred into local buildings. Also, the water evaporating from plants leads to a cooling off of the surrounding environment (in a similar way that sweating cools people off). By expanding and building green space in urban areas, there is an increase in environmental heat sinks which helps to further mitigate the urban heat island effect.

As urban populations continue to grow and urban centers continue to expand, it is more critical than ever to invest in technologies that can mitigate the effects of urban heat islands. The detrimental health effects associated with urban heat islands will continue to compound and worsen if action is not taken immediately.

Energy and Buildings (2013). DOI: 10.1016/j.enbuild.2013.04.014
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Dropping like flies

Humanity's threat to insects & the desperate need for more data

BY ELLA MESSNER,BIOLOGY & MATHEMATICS, 2023

DESIGN BY NIKKI SUZUKI, ECOLOGY & EVOLUTIONARY BIOLOGY, 2023

Our planet is teeming with bugs. Over 1 million insect species are described, and scientists estimate that another four to 7.5 million have yet to be classified. Insects account for a large proportion of animals on Earth and are nearly ubiquitous in terrestrial ecosystems. But, like so many other animals, these six-legged, exoskeleton-clad creatures are facing a crisis at the hands of human activity.

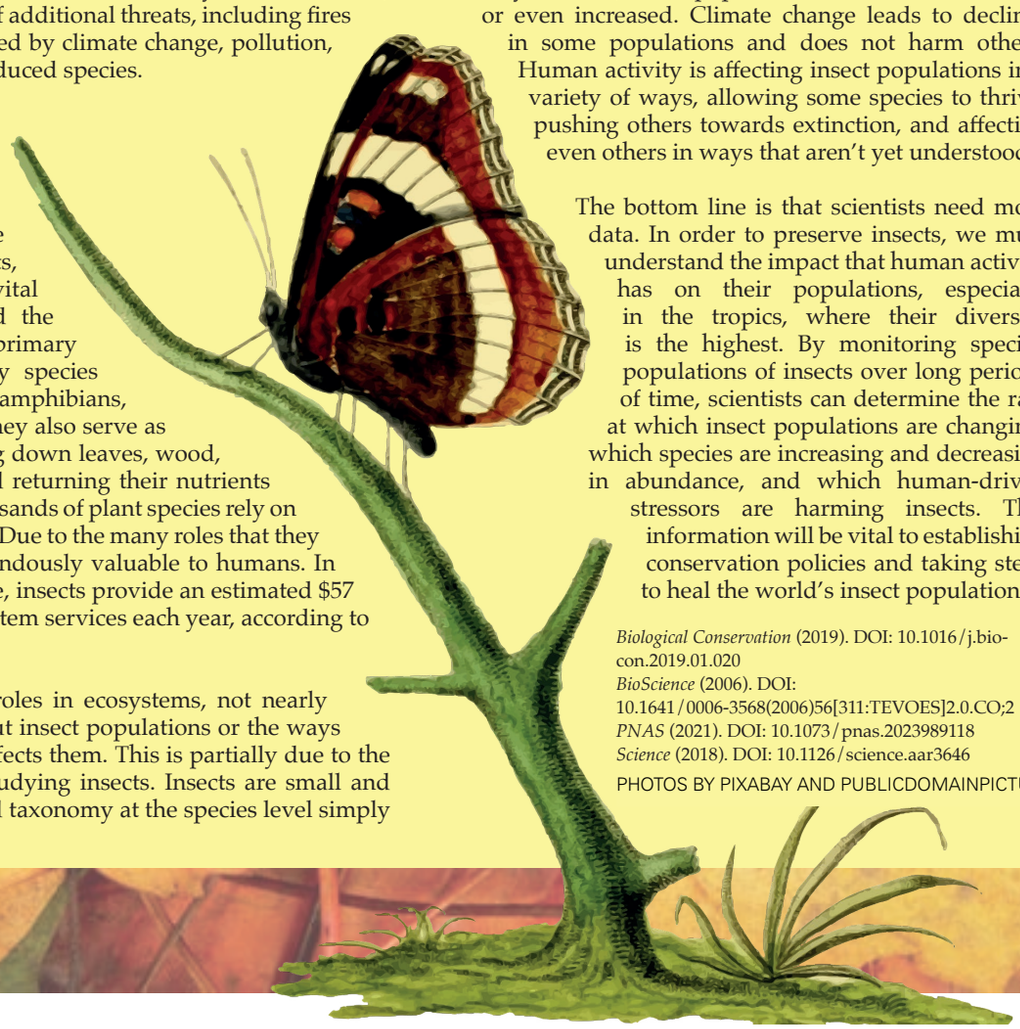
Perhaps the most pressing threat to insects is anthropogenic climate change, or the impact of human actions on the climate. Rising global temperatures have already begun to shift the habitat range of many insects, altering the regions in which different species are capable of surviving. While these changing temperatures are beneficial to some warm-adapted insect species, they ultimately threaten insect biodiversity. Scientists estimate that a global temperature increase of 3.2 degrees Celsius, which is plausible given current emission levels, would result in 49 percent of insect species losing the majority of their habitat range. In addition to loss driven by climate change, deforestation is destroying insect habitats at alarming rates. In 2019 alone, 11.9 million hectares of forest were destroyed in the tropics. For comparison, this is over four times the area of Massachusetts. As deforestation continues, more and more insects will be at risk. Beyond habitat loss, insects face a myriad of additional threats, including fires and droughts intensified by climate change, pollution, nitrification, and introduced species.

The loss of insects to these threats has the potential to be catastrophic. Although insects are often considered pests, they are actually vital to ecosystems around the globe. Insects are a primary food source for many species of reptiles, birds, amphibians, mammals, and fish. They also serve as decomposers, breaking down leaves, wood, dung, and carrion and returning their nutrients to the ecosystem. Thousands of plant species rely on insects for pollination. Due to the many roles that they play, insects are tremendously valuable to humans. In the United States alone, insects provide an estimated $57 billion worth of ecosystem services each year, according to a 2006 paper.

Despite their crucial roles in ecosystems, not nearly enough is known about insect populations or the ways that human activity affects them. This is partially due to the difficult logistics of studying insects. Insects are small and incredibly diverse, and taxonomy at the species level simply doesn't exist in many cases. This makes tracking insect populations especially challenging. The population research that has been conducted focuses heavily on the small subset of insect species that are considered significant to agriculture. Moreover, most long-term insect population data comes from the United States and Europe, areas that are collectively home to only 20 percent of insect species. Tropical regions have the highest insect diversity by far, but due to insufficient funding, data from the tropics are particularly lacking.

These biases, along with the general scarcity of long-term data, make it difficult for scientists to determine trends in insect populations. However, enough information has been collected to identify that there is a problem. Current estimates suggest that global insect abundance is decreasing by one to two percent each year. Some papers have made more dramatic claims, with one controversial review even suggesting that 40 percent of insects could be at risk of extinction in the coming decades. This claim has been widely discredited, but it sparked a wave of media coverage warning of an "insect apocalypse." Insect populations are certainly at risk, but the reality is far more nuanced than these types of sensationalized stories suggest. In some areas altered by humans, insect populations have remained stable or even increased. Climate change leads to declines in some populations and does not harm others. Human activity is affecting insect populations in a variety of ways, allowing some species to thrive, pushing others towards extinction, and affecting even others in ways that aren't yet understood.

The bottom line is that scientists need more data. In order to preserve insects, we must understand the impact that human activity has on their populations, especially in the tropics, where their diversity is the highest. By monitoring specific populations of insects over long periods of time, scientists can determine the rate at which insect populations are changing, which species are increasing and decreasing in abundance, and which human-driven stressors are harming insects. This information will be vital to establishing conservation policies and taking steps to heal the world's insect populations.



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CLIMATE CONFUSION:
INCONSISTENCIES IN GREENHOUSE GAS MONITORING

BY SOPHIA RUGGIER, BIOCHEMISTRY, 2024

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

Numerous research institutions have taken the initiative to document the concentrations, distributions, and rates at which greenhouse gases are emitted into the Earth's atmosphere. The accumulation of carbon dioxide, nitrous oxides, methane, and fluorinated gases from fossil fuel burning, industrial processes, and the agricultural industry poses a major threat to the already-depleting ozone layer. This impending crisis has prompted climate scientists to develop a diverse array of monitoring methods, including satellites, aircraft-based monitoring, and ground-based stations.

Despite these efforts, there remains one drawback: the monitoring and reporting of greenhouse gases across the world is inconsistent. There is not a standardized method for measuring emissions, according to a paper from Northern Arizona University, nor is there equal access to monitoring equipment in all areas of the world. Greenhouse gas emissions are measured through different media, according to different criteria, and almost exclusively in more developed areas with more resources.

Monitoring stations are heavily concentrated in North America, eastern Asia, and western Europe. The distribution of stations neglects Africa, South America, and the remainder of Europe and Asia and leaves gaps in emission data. These gaps result from a lack of funding for new stations combined with the prioritization of data collection in wealthier countries by major observational networks. Unless this problem is remedied, there will continue to be a skewed perception of greenhouse gas emissions worldwide and unmonitored communities will be left vulnerable.

Currently, greenhouse gas monitoring relies on self-reporting. It may not come as a surprise that cities have taken advantage of this policy to underreport their gas emissions. The absence of a standardized method leaves room for cities to omit emissions from petroleum fuel consumption and provide rough estimations of airborne and traffic emissions. A study published in February 2021 reveals a 29.1 percent mean absolute difference between the self-reported fossil fuel carbon dioxide emissions of US cities and the emissions as they have been quantified in the Vulcan Version 3.0 dataset, which provides a more comprehensive estimate.

Accurate and standardized monitoring is the first step in combating the climate crisis. Underreporting and leaving areas unmonitored will only hurt the environment in the long run and render communities unprepared for the consequences. Climate change is a collective issue: all nations must work as a cohesive unit to monitor greenhouse gas emissions and take decisive actions to reduce them, for the sake of our planet and our future.

PHOTO BY FLICKR

Nature (2021). DOI: 10.1038/d41586-021-01967-z
Nature (2021). DOI: 10.1038/s41467-020-20871-0

The Permian-Triassic mass extinction:
Does anything seem familiar here?

BY EVAN DOGUS, BUSINESS ADMINISTRATION & MARINE SCIENCE, 2025

DESIGN BY PARKER HITT, BIOLOGY, 2024

Approximately 252 million years ago, the Permian-Triassic Mass Extinction was the deadliest event to ever take place in Earth's 4.5 billion-year history. Over the course of 15 million years, the "Great Dying" wiped out nearly 70 percent of terrestrial plant and animal species and over 95 percent of marine species. It consisted of three phases which eventually increased the average global temperature by an estimated 10 degrees Celsius or 50 degrees Fahrenheit.

High levels of volcanism in Siberia marked the first phase. These extensive eruptions rocked the planet for about one million years and produced enough lava and debris to cover an area the size of the United States. Enormous amounts of greenhouse gases (carbon dioxide, methane, etc.) were propelled into the atmosphere, increasing the average global temperature by about four degrees Celsius. This increase may seem insignificant, but as temperatures rose, biotic factors like metabolism, reproduction, and homeostasis and abiotic factors like climate, weather, and resources became unbalanced. Nature exists in a delicate balance; species unable to adapt perished.

The second phase involved the abrupt death of almost all marine life. As volcanic activity raised global temperatures and carbon dioxide levels, the ocean experienced a massive chemical imbalance. Increasing ocean temperature and acidity killed nearly all marine life. As oceans heated up, water molecules moved faster, allowing more dissolved oxygen to escape. Without enough oxygen, widespread suffocation of nearly all marine life occurred.

The warmer water paved the way for the final phase. Methane-hydrate traps are ice-like solids that consist of methane and water. These traps existed beneath the ocean floor for millions of years. The rising temperatures released the traps, raising the temperature of the planet another five to six degrees Celcius. This was the final straw for many remaining species. Life only began to recover after 100,000 years, leading to the age of the dinosaurs.

History tends to repeat itself. In the Permian Period, before the extinction event, Earth experienced environmental conditions similar to modern conditions. The increased global temperature ended the widespread biodiversity and warm, moist climate. Experts project that by the year 2100 the average global temperature will have risen 4 degrees Celsius since the early 1800s. That same change previously took place over one million years. There is still time to turn things around. If we don't, this ancient extinction may happen again and we could experience a second Great Dying.

Nature (2020). DOI: https://doi.org/10.1038/d41586-020-01125-x

PHOTO BY SHUTTERSTOCK

RARE PLANT SPECIES SURVIVE THANKS TO POLLINATORS

BY CAILEY DENONCOURT, BIOENGINEERING & BIOCHEMISTRY, 2022

DESIGN BY PARKER HITT, BIOLOGY, 2024

The California Floristic Province is a region encompassing the entire coast of California and is known and studied for its incredible biodiversity. This Mediterranean-like ecosystem is the home to almost 3,500 different vascular plant species — 61 percent of which cannot be found anywhere else in the world. This biodiversity hotspot, along with other hotspot regions around the globe, keep ecologists wondering how the rare species are able to coexist with the overwhelming frequency of abundant species.

No ecologist has been able to pinpoint the answer to this question, but the primary hypothesis is that plant-pollinator interactions contribute to the phenomenon of thousands of species living in the same region without many of them going extinct.

One distinguished professor from the University of Pittsburgh's evolutionary ecology department, Tia-Lynn Ashman, has been researching and studying the plant-pollinator interactions for many years. In her recent article published in September of 2021, Dr. Ashman analyzes various hypotheses for how pollinators help maintain flowering plant diversity, including pollinator niche partitioning, asymmetric functioning, and other ecological hypotheses.

Pollen plays an essential role in plant reproduction, and therefore, the study of pollen can reveal the basis for this profound species diversity. For every flowering plant, the pollen they receive can be labeled as conspecific pollen (CP) or heterospecific pollen (HP). CP are pollen particles that are specific to that species and hold a greater precedence over HP, which are pollen particles belonging to another species. Pollination fitness is the frequency at which a plant is fertilized, and it is determined for each flowering plant species by the CP per ovule, which is the plant structure that gives rise to female reproductive cells. Therefore, the more CP per ovule, the greater ability the species has to survive and reproduce, indicating a greater pollination fitness.

Rare plants often have more specialized pollinators. Initially, this would seem detrimental, indicating fewer species are available to pollinate. However, this actually allows rare plant species to avoid HP, which can clog the stigmas, or the pollen-receptive surface. Clogged stigmas would reduce the plant's fitness. Distinct pollinators between rare and abundant species can eliminate this competitive exclusion, a phenomenon that can lead to extinction. This hypothesis is called pollinator niche partitioning, which is one of the main two theories ecologists have agreed upon to explain the maintenance of flowering plant biodiversity.

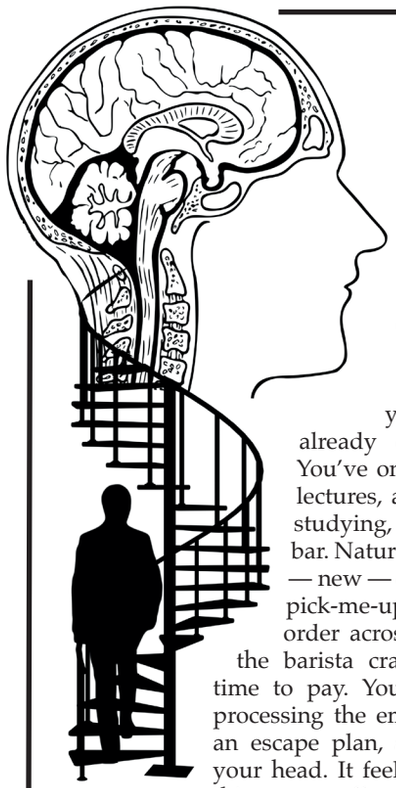
Alternatively, asymmetric facilitation is believed, in conjunction with pollinator niche partitioning, to maintain this biodiversity. Although the pollinators may be more specialized for the rarer species, there still exists some overlap. Importantly, this shared pollinator niche can favor the rare species while hindering the abundant species. Shared pollinators create the issue that CP meant for the abundant species will make its way over to the rarer species. This higher misplacement of the specific pollen particles decreases plant reproduction and fitness level. Meanwhile, the rare species are benefiting — they are receiving more CP because of the presence of shared pollinators than if they were growing without the surrounding abundant species. Thus, despite also having an increase in HP, there is an additional beneficial increase that helps outweigh the negative effects.

Two other less-explored hypotheses include pollinator assurance and numeric assurance. Pollinator assurance is based on flowering plants' ability to autonomously fertilize themselves, meaning they are hermaphrodites, containing both male and female sex organs. By increasing this ability to self-fertilize, the number of CP per ovule will also increase and thus increase the plants' fitness. The numeric assurance hypothesis shows that population increase does not increase the plant's fitness, thus having a larger species population has little to no effect on reproduction. These two hypotheses further explain how these rare populations are able to continue to coexist in the same region through detrimental pollination effects on the abundant species and beneficial pollination effects for the rare plant species.

With each experiment, Dr. Ashman was further able to show how pollinators have a great effect on maintaining the biologic diversity of rare flowering plant species. A combination of the four hypotheses prove how it is our responsibility to ensure that pollinators like bees continue to thrive. According to the Center of Biological Diversity, honeybees have decreased by a staggering 89 percent in just the past 20 years. As this pollinator population continues to rapidly decline, scientists are advocating for help in their protection — without bees and other pollinating insects, many of the rare species will likely go extinct, resulting in the destruction of some of the richest, most important ecosystems in the world.

Nature (2021). DOI: 10.1038/s41586-021-03890-9

PHOTO BY SAM KLEIN, DESIGN, 2022



FOR THE FIRST TIME, AGAIN

Investigating the neuroscience behind déjà vu

ARTICLE AND DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

The rain is pouring outside. It's only 1 p.m. on a Monday, yet you feel the day has already dragged on for ages. You've only made it through two lectures, an hour of unproductive studying, and about half a protein bar. Naturally, you end up at a local — new — coffee shop for a midday pick-me-up. After shouting your order across the bar and watching the barista craft your latte, it comes time to pay. Your card declines. Before processing the embarrassment or finding an escape plan, a different thought fills your head. It feels like you have been in this exact coffee shop before on a rainy day, ordered a latte, and had your card declined. That very moment feels like a repetition of the past; there's a glitch in your reality — déjà vu.

This phenomenon is quite common, with well over half of the population saying they've experienced déjà vu at least once in their lives. So, what actually happened to you at that moment? A popular belief is that déjà vu is evidence of the multiverse. People theorize that the phenomenon occurs because you have in fact experienced this reality before, in a parallel dimension. Although it's hard to prove a rift in alternate dimensions, there is stronger, more research-backed evidence that déjà vu is not a glitch in the universe but rather located somewhere closer to home — our brains.

Many neuroscientists have researched the phenomenon and come up with various explanations as to why déjà vu occurs. One belief is that déjà vu occurs because of temporal lobe seizures, stemming from the fact that people with temporal lobe epilepsy (TLE) typically experience déjà vu as a symptom. The temporal lobe, specifically the hippocampus, is the region of the human brain involved in the storage and retrieval of memory. P.N. Vlasov, a professor of neurology at the Moscow State University of Medicine and Dentistry, investigated the relationship between temporal lobe seizures and déjà vu, and he was able to draw a distinction between epileptic déjà vu and non-epileptic déjà vu. Vlasov compiled a case study on the epileptic and non-epileptic subjects who reported experiencing déjà vu and compared their electroencephalogram (EEG) readings. He found that in epileptic subjects, there is a definitive random and extensive neuron firing in the various regions of the temporal lobe. In other words, pathologic déjà vu is a result of excessive neuron firing or a simple partial seizure. However, the same neuron firing pattern was not picked up in the EEG of a non-epileptic patient experiencing déjà vu, meaning they did not have a seizure.

This raises the question, why do non-epileptic people experience déjà vu?

A 2015 research experiment conducted by Dr. Akira O'Connor, a professor at the University of St Andrews, and others reveals an entirely new explanation of déjà vu. Rather than being a malfunction of perception and memory recall, déjà vu is an active process of decision making within the frontal lobe. O'Connor used fMRIs to image subjects' brains while inducing feelings of familiarity or déjà vu. The results showed regions of interest (ROIs) in the prefrontal and parietal regions. Further, "analyses confirmed that, within the prefrontal and parietal ROIs, the response of 'conflict'-affiliated subregions to cue strength peaked significantly earlier than the 'retrieval'-affiliated subregions' response to confidence." In other words, when déjà vu is experienced, the brain is initiating a conflict-resolution sequence or decision-making process, prior to memory retrieval.

The significance of this new research regarding the neuroscience behind déjà vu is an insight into the functioning of the brain. Déjà vu is the brain having a conversation with itself, checking in on its own memory recall accuracy and ability. When the brain perceives familiar environmental stimuli, it engages the decision-making process — the prefrontal cortex — to determine whether the experience is actually a familiar memory. This may elicit memory recall, but it is secondary to the initial "conflict"-affiliated prefrontal and parietal subregion involvement.

So, what exactly happened as your card declined at the coffee shop? Although there's no conclusive answer just yet, it's likely that your brain was talking to itself, trying to figure out if everything it perceived is also stored in your memory. What we do know, definitively, is that this glitch — déjà vu — gives us insight into how our minds perceive and remember our experiences, and it may not be such a bad thing after all.

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PHOTO BY PIXABAY

THE QUESTION OF THE PERFECT-PITCH BRAIN:

REVEALING HOW WE PROCESS SPEECH AND MELODY

BY TENZING BRIGGS, ENGLISH, 2022
DESIGN BY RESHIKA SAI DEVARAJAN, HEALTH SCIENCE, 2025

In the world of music, being able to know when you're in tune is key. As any musician knows, it takes a good deal of time, skill, and experience to identify tones, and in most cases, one needs a reference tone, having "relative pitch." However, some have the ability to identify notes without any reference. Those with this ability are colloquially known as having "perfect pitch" or "absolute pitch." Across studies on perfect pitch, some have shown certain trends behind the phenomenon. A primary trend is that the prevalence of this skill differs across cultures, with it being less common in Western cultures than in some Eastern ones, suggesting culture and training are key factors. For example, Japan in particular has had much higher prevalence in its population. Among Western musicians, between 1 and 20 percent of the population has perfect pitch; while in Japan, up to 50 percent has it. Similarly, China has reported higher rates of perfect pitch individuals than the United States has across all age levels.

What at first seems like a random disparity is likely the product of consistent cultural, linguistic, and musical traditions acting upon the young mind's high level of adaptability. Specifically, in Japan, the Suzuki method of violinist training is thought to increase the probability of gaining perfect pitch, while in China it's thought to be influenced by learning the heavily tonal language of Mandarin.

> "How might memorized melody be like the intonations of complex tonal speech, and what is the overall effect of that on the brain when taught at an early age?"

The Suzuki method generally trains musicians at an especially young age, usually before five, with an emphasis on learning music through melody memorization and purely auditory cues; students aren't taught sheet music notation first. This points to something shared with young Chinese students. Music learned by this method is, in some ways, akin to learning a language, since there are no visual cues, and because learning Mandarin requires mastering subtle tonal differences, these two populations share two things: One, they're exposed to tonal differences at an extremely young age, and two, that exposure takes place in a way that shies away from visual cues.

Neurologically, the union of these two trends hints at meaningful understandings of auditory and musical processing. How might memorized melody be like the intonations of complex tonal speech, and what is the overall effect of that on the brain when taught at an early age?

One 2019 study in the *Journal of Neuroscience* compared brain matter and neural activity between those with perfect pitch and those without (both relative pitch and control subjects) when asked to identify tones. It found that people with perfect pitch have a larger amount of neural tissue in their auditory cortex and that neural tissue was more "broadly tuned" when listening, a term that refers to the activity of neurons. Neurons with broader tuning are more reactive to a broader range of stimuli. This suggests that those with perfect pitch are more attuned to auditory stimuli; by having more reactive tissue, they are more perceptive of a stimulus's qualities.

But studying differences in neural activity across different *kinds* of auditory inputs reveals a more intricate picture. Instead of recording activity on just tone identification across the groups of those with perfect pitch, relative pitch, and a control group of nonmusicians, one 2010 study published in *Cerebral Cortex* study looked at how each of these three groups reacted to a broad range of speech stimuli, varying in lexical (e.g., vocabulary) and prosodic (e.g., rhythm and intonation) makeup. Different hemispheres of the brain have been shown to activate for segmental versus suprasegmental information processing — left and right, respectively. Segmental information processing refers to distinct sound units like *p* or *t* that change lexical meaning, like *pad* versus *tad*. Suprasegmental processing occurs with changes in stress and tone, which are melodic elements. This second study, then, compared participants' brain activity when listening to speech and melody and found that, when listening to both, perfect-pitch brains had, on average, different brainwave frequencies across *both* hemispheres compared to relative-pitch and nonmusician brains. With each hemisphere associated with either lexical speech or melodic elements, this implies that part of perfect pitch is processing not just melody differently but speech as well.

In other words, this study was able to prove that, on some level, those with perfect pitch process *both* speech and melody differently; these might both contribute to perfect pitch. It seems they can hear the music of the world in a way that others can't, almost linguistically, possibly because they've been taught to since such a young age.

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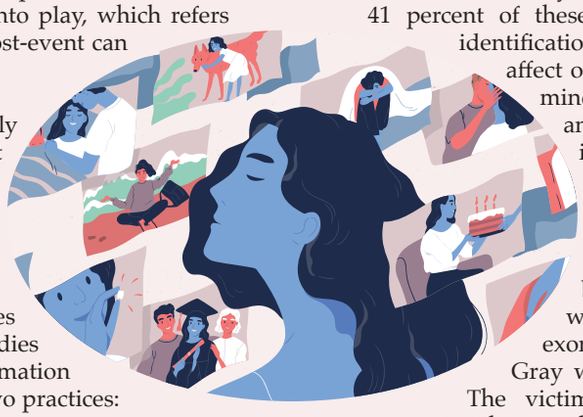
PHOTO BY SHUTTERSTOCK

The fallibility of memory and the misinformation effect in eyewitness testimony

BY MCKENNA FORREST, BIOLOGY & CRIMINAL JUSTICE, 2023 DESIGN BY SOPHIE PATE, BEHAVIORAL NEUROSCIENCE, 2024

Anyone who has watched "Criminal Minds" is familiar with the iconic cognitive interview, where the team members attempt to re-immerse a witness into the crime scene by asking them to recall specific details surrounding them. The interview almost always results in an incredible moment where the witness suddenly remembers exactly what happened. However, memory retrieval is not that simple, and it is not always accurate. Memory is influenced by our own biases and ideals in the same way we judge characters in our favorite tv shows. When memory is retrieved and an event is recalled, a phenomenon known as the misinformation effect comes into play, which refers to how exposure to information post-event can interfere with the original memory.



The fallibility of memory is especially important when put in the context of eyewitness testimony. First, the stakes are incredibly high; the decision of whether or not to imprison someone is not something to be taken lightly. Additionally, eyewitness testimonies are especially interesting case studies for the consequences of the misinformation effect because they fall victim to two practices: the repeated retrievals of memory common in interrogations and retrieval-enhanced suggestibility (RES). RES refers to the phenomenon that an immediate test of memory after a witnessed event can increase vulnerability to misinformation.

One study from Iowa State University in 2017 looked at levels of inconsistency and inaccuracy of memory for participants who witnessed a crime and were subjected to different stages of questioning. Results showed that there was indeed a substantially greater reporting of misinformation during the final memory test for witnesses who were questioned about the event immediately after it happened compared to those tested a week after. These results highlight the RES effect, suggesting delayed initial testing can improve memory performance. The study also found that those who chose the correct information versus the misinformation rated themselves with approximately the same confidence levels, even though participants selected the misinformation 76 percent of the time. These results are a bit shocking and worrying, especially when the confidence of eyewitnesses is often one of the biggest influences that jurors take into account, according to a 2011 study in Psychology, Crime, and Law. It is often believed that the biggest sign of a poor, unreliable witness is a lack of confidence, but the results of the 2017 study force us to reconsider.

Eyewitness testimony can be very dangerous. In the book "Convicting the Innocent: Where Criminal Prosecutions Go Wrong," the author, Brandon L. Garrett, tells the stories of several individuals wrongfully convicted by eyewitness misidentification. As of 2017, approximately 350 convictions had been overturned by DNA findings, and about 70 percent of the trials involved eyewitness testimony. Shockingly, in 41 percent of these cases, there was a cross-racial identification. Not only do our own biases affect our memory, but it must be kept in mind that the biases of police officers and investigators have significantly impacted criminal trials for centuries. In 2004, Uriah Courtney was arrested for assault. The only evidence? Two eyewitnesses who swore under oath were positive beyond a shred of doubt that he was the guy. Nine years later DNA exonerated him. In the 1970s, David Gray was on trial for rape and murder. The victim testified she was "absolutely positive" he was the attacker. He wasn't, and it took him 20 years behind bars to prove it.

Another recent study by the Departments of Psychology at Fairfield University and Tufts University aimed to measure how different warnings can reduce susceptibility to misleading information. Participants were warned at different stages that some of the information they were exposed to after watching the event was wrong. Results suggested that warnings to errors both pre-exposure and post-exposure can significantly reduce misinformation.

Where do investigations go from here? There is finally research being done to learn about possible improvements to investigative strategies. But, when it comes to witness testimony, the risk may be greater than the reward. As forensic science continues to advance and DNA is easier to analyze than ever before, perhaps it's time for eyewitness testimony to be retired as an evidence source. Trials must prove the accused guilty beyond any reasonable doubt, but science proves that our memories are shrouded with doubt, and a degree of certainty for our own memories may never be feasible.

PHOTO BY UNSPLASH

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THE NEUROLOGICAL GLITCHES BEHIND STUTTERING

Causes and arising treatments

BY KYLE JONES, BIOCHEMISTRY, 2024

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Including President Joe Biden, Emily Blunt, and James Earl Jones, stuttering affects over 70 million people, including 3 million Americans. Denoted by continuous interruptions in the starting and timing of syllabi, stuttering can have dramatic effects. About five percent of children stutter, but approximately 80 percent recover from stuttering by the time they reach adulthood, resulting in one percent of the world's adult population being stutterers according to a 2004 study in PLoS Biology. Additionally, with adults, there are four times as many male stutterers as female stutterers. While scientists are still not certain on the exact causes of stuttering, there are new theories behind stuttering's origin, such as issues in brain circuitry, excess dopamine absorption, and even genetic inheritance.

One section of the brain's circuit system that may be unique in those who stutter is the default mode network. The default mode network, which is involved in analyzing the past and contemplating the future, seems to interrupt the signals between the areas of the brain that take part in formulating movements and attention to tasks. Literally, the brain interrupts its own signals, and this is translated into interruptions in speech patterns.

There may also be a genetic connection to stuttering. Researchers investigated a region of chromosome 12 in those who stutter, and a mutation found in the GNPTAB gene may be connected to stuttering. Investigating a largely inbred family, a 2011 study by Dennis Drayna and Changsoo Kang found that a single mutation in the coding sequence of the GNPTAB gene resulted in the insertion of a positively charged lysine amino acid in place of a negatively charged glutamic acid component. Since an analysis of the GNPTAB protein in all other species revealed that glutamic acid was present, it was inferred that this small change has substantial effects on the functionality of the protein. When investigating other individuals, the same mutation was common in other stutterers and was not present in non-stuttering control subjects. Mutations in the GNPTAB gene have been linked to diseases that cause degeneration of bodily tissue, including the brain. In severe mutations, individuals do not live long and never develop the ability to speak. It is hypothesized that a smaller mutation in the GNPTAB gene may lead to issues in speech development, but further studies are needed to test the biochemical functionality of the mutated enzymes and determine if these result in stuttering.

Another arising theory behind the cause of stuttering is excess dopamine activity in the basal ganglia, a complex network in the brain that is involved in the control of movement. Stuttering has overlapping symptoms to Tourette's syndrome, a movement disorder where individuals experience an involuntary expression of actions and vocal sounds. Tourette's syndrome has been associated with excess dopamine and therefore has been treated with antidopaminergic drugs such as olanzapine and risperidone, according to a 2014 study in *Hospital Pharmacy* and a 2018 study in *Psychiatry and Neurological Sciences*. Antidopaminergic drugs suppress dopamine receptors' ability to absorb dopamine and have also been implemented in treating some individuals that stutter. So far, results have been strongly positive for reducing stuttering. However, there are also issues with olanzapine and its possible role in *inducing* stuttering in individuals reported in a case study from the Ankara Numune Training and Research Hospital in Turkey. A new drug, ecopipam, appears to suppress D1 dopamine receptors, which may relieve some of the harsher side effects of the other antidopaminergics. In a research study of 10 volunteers, ecopipam appeared to be effective in lowering the number of syllabi stuttered in the volunteers, with an average decrease of nine percent of syllabi mispronounced before and after taking the drug for eight weeks. However, much more testing is required to verify the effects of ecopipam on stuttering.

Overall, stuttering is still not very well understood, but research is in the works to improve the livelihoods of those affected by the condition. New therapies and drugs are being investigated and show positive results, so it may not be long until stuttering is a glitch of the past.

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PHOTO BY SHUTTERSTOCK

When fear processing goes wrong

ARTICLE AND DESIGN BY VIANNA QUACH, PHARMACEUTICAL SCIENCE, 2025

Our brains are amazing. We use them to store and process a variety of information, react better, learn to respond to our environment more efficiently, and survive. Emotions play a large part in this. These reactions to stimuli are processed by the brain, inducing a physiological reaction and emotional response. Oftentimes, these emotions are regulated by the brain, but when they aren't, these emotions — either in excess or deficit — can cause psychological disorders. Looking at fear processing can provide insight into how this may occur.

Fear is one of the most complex pieces of information our brain processes. This primal feeling has kept the human race alive, acting as a warning to escape or protect ourselves from danger. How exactly does this occur? When something from the environment stimulates a fear response, it is first received by a region of the brain called the thalamus, which acts as a gateway that distributes signals to other relevant regions of the brain to initiate an appropriate response.

One major region of the brain's limbic system, the amygdala, is responsible for processing these stimuli and sending signals to the rest of the body, initiating physiological and behavioral reactions. A 1995 study conducted by Yale University supports this connection between the amygdala and fear. In the experiment, researchers found that in order to produce a fear response (measured by physiological changes such as increased heartbeat), the lateral nucleus and the basolateral complex of the amygdala are necessary for relaying sensory information from receptors, such as eyes, to the central nucleus of the amygdala for the receiving and processing of fear stimuli.

Once the amygdala has processed the fear stimulus, it will send neurochemical signals to other regions in the brain as well as to the endocrine system, which is regulated by the hypothalamus and the pituitary gland. This activation of our sympathetic nervous system serves to release hormones in the body, which is important for initiating the stress response in the body and inducing the physiological feelings related to fear (including increased heartbeat, blood pressure, alertness). This prepares the body to handle the source of fear.

The brain's prefrontal cortex, responsible for our higher-level thinking capacity, also works in regulating our fear responses. Unlike the amygdala, the prefrontal cortex primarily functions to reduce the body's response to fear stimuli and to help the brain in controlling emotional responses.

Because there are many different processes and structures that work to regulate fear in the brain, there are also many different ways for it to go wrong. The amygdala's function, for example, requires a delicate amount of sensitivity. Although activation of the amygdala is important for generating fear and detecting threats, a hyperactive amygdala has been linked to anxiety in adults. Similarly, hyperactivity in the right prefrontal cortex has also been associated with anxiety. This abnormal amount of stress put on the body is detrimental to both a person's physical and psychological health, creating feelings of constant uneasiness and fatigue, inhibiting their ability to function in daily life. Alternatively, a dysfunctional or damaged amygdala could potentially result in reduced fear and an inability to detect fear from others.

No matter how amazing our brains are, they are still susceptible to glitches. As with other chemical processes and emotions, fear is a feeling that the brain must carefully regulate to keep us functioning properly in our daily lives.

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PHOTO BY ANNA TORTEN RABINOWITZ, BIOLOGY, 2024

The Science behind lucid dreaming: Is waking insightfulness correlated?

BY VINITHA VIVEK, COMPUTER SCIENCE & COGNITIVE PSYCHOLOGY, 2025

You are sitting in your English class when the teacher announces that you have a pop quiz on the "Macbeth" reading from last night. This was the same reading you procrastinated the previous night because scrolling on TikTok in bed was far more appealing. The overwhelming and endless amount of doomful scenarios going through your mind are unmatched by the silence surrounding you in the classroom.

But suddenly, something clicks.

This isn't real. This was all a dream. Relief.

The half-tiger-half-bird sitting at the desk to your right should have given it away sooner.

If you have ever become aware that you are dreaming while in a dream, you have experienced lucid dreaming. Lucid dreaming is correlated with heightened prefrontal cortex activity resembling the level of brain activity when awake. Roughly half of all adults have had a lucid dream at least once in their lives. About 20 percent of adults experience lucid dreaming monthly, and just 1 percent have been in this perplexing state several times a week.

Lucid dreaming exists on a spectrum that can be experienced on varying levels. Deep lucid dreamers can alter the sequence of events, people, or places in their dreams. For instance, these dreamers can transform a scene from their living room into the Amazon rainforest. However, most lucid dreamers cannot cause this transformation and will only be aware that they are dreaming. Although experts still do not know the exact reason why some people lucid dream more frequently and more deeply than others, noteworthy correlations have been found between high levels of awareness while awake and frequent lucid dreaming.

A study conducted by Dr. Patrick Bourke and his student, Hannah Shaw, compared participants who had frequent lucid dreams to participants who did not. They measured the "insight" level of participants by testing them with word association games. These games required the participants to find one link between five seemingly unrelated words. Not unexpectedly, Bourke and Shaw found a correlation between the ability to crack these puzzles and the frequency of lucid dreaming in participants.

To recognize that you are in a dream state certainly requires a deep level of insight, but can this type of "insightfulness" be measured merely through word association games? Scientists are continually trying to find the right tests to analyze and understand lucid dreaming, but until then, this phenomenon remains mystifying.

Dreaming (2014). DOI: 10.1037/a0036908

COLOR

The most beautiful lie ever told

BY PATRICK J. DONNELLY, ELECTRICAL & COMPUTER ENGINEERING, 2026

Everyone knows the color wheel; red, yellow, and blue combine to make orange, green, and purple, all of which combine to make the spectrum. While this system works well for understanding pigments, it breaks down when considering mixtures of light, where red and green make yellow and white is a tertiary color.

To explain these inconsistencies, we turn to color theory, which aims to understand the mixing of colors across all media as well as the mechanism by which we see color.

In 1801, Thomas Young, an English polymath famous for his work on light propagation, became among the first academics to propose a trichromatic theory of light. While earlier minds like Isaac Newton believed the human eye saw every color individually, Young posited the eye saw three color primaries: red, yellow, and blue.

As it turns out, the human retina detects light via two types of photoreceptors: cones and rods. Rods measure light intensity and are responsible for monochromatic vision, while cones measure color intensity. Cones come in three varieties, L (long-wavelength), M (medium-wavelength), and S (short-wavelength), which detect red, green, and blue intensity, respectively. Our perception of chromatic hue is the brain's interpretation of the mixture of these three signals.

However, this process can go awry. Since the brain relies on mixed signals to deduce a color's place on the spectrum, when an impossible combination occurs, the brain "short-circuits." Most famously, when the brain experiences red and blue signals but no green, the result is magenta, even though the color lacks an associated wavelength. Inversely, the sudden removal of a continuous stimulus will produce an afterimage dubbed a *chimerical color.* For example, when a yellow signal is suddenly switched to black, the resulting afterimage will be an impossibly dark color called stygian blue.

This overview only scratches the surface of one particular theory of vision, known as Young–Helmholtz Theory. Though one of the most popular theories of color perception, it fails to explain chimerical colors, as the color wheel fails to explain light.

Nevertheless, we see magenta, even when it theoretically should not exist. Though an elementary concept, color is not fully understood, with current research exploring its perception as additive, subtractive, and even psychosomatic. As this corpus of knowledge grows, so shall our theories of color, parsing the brain's beautiful lie.

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DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

DYSLEXIA: DISADVANTAGE OR ADVANTAGE?

BY LOUISE HOLWAY, ARCHITECTURE & CIVIL ENGINEERING, 2022

DESIGN BY PARKER HITT, BIOLOGY, 2024

The brain-machine interface is one of the most intriguing yet enigmatic research endeavors being tackled today. At first glance, it can seem like an overwhelming concept; a seemingly distant probability of a future reality. The truth is, people are already living in an age where the lines between humans and artificial intelligence are blurred.

Neuroprosthetics and neural implants are extremely significant areas of focus for many experts in biotechnology. Many advancements have been made in the field, such as widespread access to devices like cochlear implants for people with hearing loss not involving damage to the auditory nerve. The fondly-named bionic eye has also demonstrated success in replacing a damaged eye and restoring vision.

Perhaps one of the most popular neural implant technologies in use today is dedicated to alleviating the motor deficits of Parkinson's disease. Individuals with this disease commonly experience abnormalities in motor control such as tremors, rigidity, and slow movements that make daily life and activities difficult. In pursuit of a treatment for Parkinson's, scientists are using neuroprosthetics to deliver deep brain stimulation (DBS). It works using electrodes implanted inside the brain in particular areas involved in the initiation and control of movement. While this strategy does not target the underlying disease itself or slow its progression, it has been shown to significantly improve motor symptoms and increase quality of life for Parkinson's patients.

Vanderbilt University Medical Center (VUMC) is a leader in the advancement of DBS procedures, having reached the milestone of 1,000 patients treated as of 2016. Dr. Peter Konrad, Professor of Neurological Surgery at VUMC, praised the program—of which he is an integral member—in an article from the center's news outlet, "We have probably the largest number of patients that have come through." A member of Konrad's team, neurologist Dr. Fenna Phibbs, also emphasized the importance of an interdisciplinary team dynamic: "It is not one-person driven. It is not one-specialty driven. What drives us is giving the best therapy for the patient."

The future of neuroprosthetics is full of promise, but it is also riddled with challenges as well. Researchers studying Parkinson's acknowledge that there needs to be a safer, more reliable way of inserting electrodes and other neural probes into the brain that does not involve invasive surgical implantation. Similarly, many of these neural devices are powered by batteries that have a shelf life. Then, surgery is required to replace the battery source, and for many that could mean countless subsequent surgical procedures over their lifetime.

Part of this research focuses on the development of biologically safe and effective materials to create devices to live inside the human body. These materials need to be non-toxic and also biocompatible so they can function symbiotically and prevent immune system rejection of the foreign material.

Researchers are also channeling their efforts into creating prosthetic devices that are even smaller in size with greater power and capabilities. An integral aspect of neuroprosthetic development is allowing the implant to interact with the brain in a more compatible way. Recently, supported by the National Institutes of Health's Brain Research through Advancing Innovative Technologies (BRAIN) Initiative and the National Institute of Neurological Disorders and Stroke (NINDS), a team of researchers and doctors documented preliminary clinical efficacy of a deep brain stimulation implant for Parkinson's disease patients that can simultaneously monitor and modulate brain activity. By monitoring the brain's own electrical output, the device can more effectively modify its performance to only stimulate the brain when necessary depending on the feedback received from recording electrodes. This adaptive method allowed for the neural implant to conserve battery energy because it turned off when it did not need to stimulate the brain. It also prevented the patient from experiencing unintended effects of the constant stimulation.

Breakthroughs like this indicate just how efficient neuroprosthetics could become and how much improvement is required to get there. Soon there may be prosthetics specifically for the optic nerve or visual cortex as a way of restoring sight for those who are visually impaired. Limbic system implants may be able to help victims of post-traumatic stress disorder recover by interfering with traumatic memories. Epilepsy, Alzheimer's disease, mental illness, and forms of brain injury may all one day be easily treated with neuroprosthetic technology. The future applications of implantable prosthetic devices for the brain are seeming boundless, not only for the treatment of serious neural conditions, but eventually for the enhancement of common brain functions.

PHOTO BY PIXABAY

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Trusting the dialectics of science

BY BINH DANG, ENGLISH, 2022
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

In many ways, science is a discussion. Many within the community know all too well about the rivalries and bickerings between academics and scientists, the workplace politics that plague every human endeavor. However, the way that we're usually taught science emphasizes facts: 1 + 1 = 2, the Earth is a sphere, and gravity will bring you back down to Earth if you jump up. Science is observation: a summary report of what we learned and what we know now. Yet science is very much a subject, living and acting, shaping the discussion as much as it is the object of the discussion. Science as a process is nothing new, but it's an idea that's often forgotten. We laugh at the people back in the Bronze Age who thought the Earth was flat, but it was just as necessary to have that idea as it was to pose a contrary hypothesis that the Earth was spherical. Our tentative knowledge of Earth's shape was imperfect, but it created a space to justify that position. Empiricism and the scientific method paved the way for finding evidence to support the hypothesis of a round Earth, and now that fact is solidified in our repertoire.

Some cases are less clear, and the discourse is more hotly contested. For example, the concept of species taxonomy isn't as absolute as the shape of the Earth. There are at least a dozen species concepts that might classify a single organism as many different, distinct species. While it might be easy to tell a human apart from a dog, it's more difficult to tell different mosquito species apart. Based on morphological characteristics, six species of Anopheles were misclassified as a single species, but genealogical data shed light on that mistake and corrected it.

The imperfection of taxonomy highlights the tentative nature of scientific knowledge, and as our methods for discovering evidence improves, so too does our understanding of the world. Scientists create arguments and support them with the best available evidence. However, new arguments and explanations can come along as we build upon others's work, and as a result, those new arguments can defeat older ones. This does not mean that science is completely futile and untrustworthy; it means that knowledge should be analyzed. Critically analyzing scientific conclusions is an important skill. Doubt and skepticism should not aim to reject and abandon but iterate upon what is already known — that is, evidence should be presented in a more convincing way to support a better conclusion.

A few questions present themselves for the layperson: If science is so tentative and uncertain, why should they trust scientists and the scientific community? Why does the scientific method provide the best evidence for knowledge about the world?

Trusting science means trusting that empirical evidence is the best way to develop knowledge about the world, and one of the best ways to learn about one's surroundings is through the senses. At the most fundamental level of comprehension, we have to trust our somatic senses and our observations. Science offers us the ability to systematically collect data and confirm or reject our predictions based on that fundamental way of knowing. Conclusions about those predictions are based on repeated observations; if you see something enough times, likely, that's always the case, but there's always room to be proven wrong.

The standards for producing statistically significant results are rigorous, and they help the credibility of science, but accountability to the community also contributes to that. Peer review is an essential part of research and publishing in academic journals because it maintains the scientists's and the journal's credibility. Independent scientists rely on the quality data of others to develop their own findings and papers, so they have a vested interest in supporting the best available research. While the peer-review process does not catch every paper and journals may issue retractions, a journal's openness to admit their mistakes is a reason to trust that the knowledge they're disseminating is sound.

Science looks for an answer, and the contention inherent in the field is exactly why it should be trusted and questioned, not questioned and dismissed. Scientists' shared pursuit of knowledge and the process's integrated skepticism and criticalness are crucial to the field maintaining its accountability and credibility. Although some spread misinformation in bad faith, there will always be a greater community of truth-seekers.

Systematic Biology (2017). DOI: 10.1080/10635150701701083

Remember your past to secure your future

How decisions about refugee status rely on the brain's unreliable memory system

BY CATRIN ZHARYY, BEHAVIORAL NEUROSCIENCE, 2023 DESIGN BY LILLIE HOFFART. ENVIRONMENTAL SCIENCE, 2022

According to the United Nations Refugee Agency, in 2020, 82.4 million people worldwide were forcibly displaced from their homes, almost double the number in 2010. Forty-two percent of displaced people in 2020 were children.

The number of refugees worldwide is rising, but the US is accepting fewer and fewer. In fiscal year (FY) 2020, among all who were able to file a claim for asylum (for which refugees already in the US apply), only 26.3 percent were accepted. This cannot be entirely attributed to the country's leadership at the time because in FY 2021 — during which the Biden administration raised the refugee ceiling from 15,000 to 62,500 — only 11,411 refugees were admitted.

Per the Immigration and Nationality Act, the only thing that should decide whether someone is granted refugee or asylum status is if the individual has "experienced past persecution or [has] a well-founded fear of persecution on account of race, religion, nationality, membership in a particular social group, or political opinion." Unfortunately, human imperfection gets in the way of implementing the law to the same degree of written precision. Refugees may not have crystal-clear memories of their traumas for a variety of reasons and the natural mistakes they make are often misinterpreted as signs of lying by even the most well-meaning immigration officials. Even if you're not a refugee, your memory is far from perfect.

Memory, both what one remembers and how one remembers it, is flexible. Your brain encodes only what is useful at that moment and what, based on experience, is likely to become useful in the future. An experience is even warped by how many times you've recalled it. Outside information can add to or distort one's version of events, whether it comes from the news or other people. But one doesn't need to hear a detail from the news or another person to accept it as part of their memory. A 2001 study quizzed 11 people on their diary entries from 10 years prior and found that 21.5 percent of 514 fabricated events distributed across all participants' questionnaires were believed to have happened.

Ordinary people are often terrible at remembering the date, duration, frequency, and chronology of an event. Furthermore, when one recalls a certain event, their idea of what really happened is warped by their current feelings and worldview. The evolutionary function of autobiographical memory is to help one keep social bonds, define one's sense of self, and guide present thoughts and behaviors; a refugee's memory has a different function before and after migration because their relationships, identity, and routine have turned upside-down.

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Refugees may have also experienced trauma and feel depressed, helpless, angry, and anxious, which further disrupts memory. A 2021 analysis of medico-legal affidavits of 193 asylum applicants found that 69 percent had post-traumatic stress disorder (PTSD), and 55 percent had depression. The same review found that people with PTSD or depression were three times more likely to have memory issues. A review of autobiographical memory and mental health research on refugees and asylum seekers published in 2021 found that people with PTSD and depression have trouble with their autobiographical memory and have more overly-general or incomplete memories compared to people without these afflictions.

Nevertheless, there is a lot of conflicting research about how stress, trauma, and PTSD affect memory. This is likely because of how uniquely PTSD manifests and people process their trauma. People can suffer from intrusive thoughts, causing them to re-experience traumatic events and be unable to recall those events due to functional avoidance. Trauma can also have lasting effects on cognition — one's thinking, working memory, mood, and attention.

Typically, immigration judges and asylum adjudicators assume refugees are lying when they struggle to remember details and maintain a consistent narrative. But, as we've learned, these are difficulties even faced by non-traumatized people, and it's inaccurate to assume that people should have precise memories of their traumas.

There are a variety of ways that law enforcement and legal professionals can better understand refugee claimants: by learning about basic memory processes, the diversity of PTSD symptoms, and cultural differences, and by practicing non-adversarial behavior. There are even proposed strategies for asking questions in a particular way and order to get the most accurate information.

The Biden administration has set the refugee cap for FY 2022 to 125,000, the largest since 1993. The United States will have more opportunities to accept refugees, thereby changing and saving lives.

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REALITY CHECK: ARE WE LIVING IN A SIMULATION?

BY CARA PESCIOTTA, PHYSICS, 2022

"**O**nce, Zhuang Zhou dreamed he was a butterfly, a butterfly flitting and fluttering about, happy with himself and doing as he pleased. He didn't know that he was Zhuang Zhou." Zhuang Zhou wakes up from his dream and finds himself back in his body, but then he comes to the strange realization that he could very well have just fallen asleep and be a butterfly dreaming he was Zhuang Zhou.

This ancient Chinese story called "The Butterfly Dream," written by philosopher Zhuang Zhou himself, calls attention to the mystery of reality, a theme that continues to be discussed today. Only, today's discussion does not just involve dreams but physics, variables, and computers. Zhou's dilemma is one of the precursors to the modern-day simulation hypothesis.

The simulation hypothesis is the idea that our universe is an artificial simulation (a la "The Matrix"). Conspiracy theorists, philosophers, and physicists have devised constraints, tests, and explanations to try

to substantiate the theory, but it remains a contentious issue within these communities.

The most prominent philosophical rationale is from Nick Bostrom at Oxford University, deriving a trilemma, the simulation argument, where one of three statements must be true: There are practically no civilizations capable of running advanced simulation, civilizations that hold the power are simply not interested, or most civilizations are simulated. This implies a one in three chance that we are simulated, assuming we are included in the majority of civilizations in the third scenario. Columbia University astronomer David Kipping, though, saw an opportunity to use Bayesian inference, a statistical theorem, to combine Bostrom's first and second postulates since they both result in a base reality. The method uses prior assumptions to better predict probabilities, and it increases the odds to a 50-50 chance.

With the likelihood being equal, believers and conspiracy theorists have proposed a number of physical phenomena in favor of simulated reality. For example, some hypothesize that a sign of computer processing in our world is a point at which processing speed reaches its upper limit. This point would be seemingly arbitrary to those inside, as it cannot be explained by physics nor can it be superseded under any circumstances since it is an artifact of hardware. Sound familiar? It is strikingly the speed of light. This constant represents the maximum amount of information — 299,792 kilometers — that can be rendered in a given second, and it prevents us from travelling faster than the universe can be produced.

> "This probabilistic nature inherently contradicts our current computing methods and thus is an incomplete explanation for artificial reality."

If a tree falls in a forest and no one is around to hear it, does it make a sound? Another rendering rule generally used in video games is that the only things rendered are those that are observed. Believers in the simulation hypothesis would argue that the tree does not actually exist — at least not until someone looks at it. This optimization strategy compensates for finite computing power. It can also be used to reconcile Schrödinger's cat in that the cat does not need to be rendered until observation and therefore is both alive and dead until that time.

Of course, these explanations oversimplify the complexities of quantum mechanics and fall victim to logical fallacies. Justifying anything, including the speed of light, with a "higher being" or program code is a circular argument and does not work to prove or disprove our lived reality; that alone cannot be reason to believe the simulation hypothesis. But the physics of these claims do not hold up to scrutiny either.

Today's computer runs on classical bits, or discrete values of 0 or 1. In order to build a world from these parts, that world must also operate on a binary where things, down to very small particles, either are or are not. From what scientists have observed, this is not how our world works. Quantum objects, for example electrons, exist in a state of superposition, meaning they exist in multiple states at once, at least until other particles, like measurement tools, interact with them. Since we cannot measure the objects without them collapsing into one state, scientists instead map the probability that the object will collapse into each state. For Schrödinger's cat, the cat described as alive and dead is an artifact of the superposition of those equal probabilities. This probabilistic nature inherently contradicts our current computing methods and thus is an incomplete explanation for artificial reality.

Lucky for believers, scientists are developing a probabilistic bit in order to produce faster computers. While their aim is to process big data rather than start a conscious simulation of their own, the invention could be a step in that direction. The unit, called a qubit, allows for superposition and probabilities to be introduced to computer processing. The latest development in quantum computing is the smallest and most accessible device to date to use qubits from the University of Innsbruck, although there is still a long way to go before it finds a place in your home. Scientists will also need to reconcile how complicated concepts in physics like general relativity and quantum field theory can be defined by quantum systems and qubits. MIT physicist Xiao-Gang Wen was successful at reconciling the Standard Model in 2012, but there is a lot of work to be done before the theory of general relativity can be unified with quantum mechanics. Since general relativity considers time to be a flexible fourth dimension, this will involve a deeper understanding of how particles interact with time.

A dilemma that started with a dream has unraveled into an entanglement of speculation and misconceptions. Logistical concerns prevent us from finding the answer right now, but many wonder whether the answer is knowable, and others question if we would want to know at all. Are we players in a game? Does our purpose change with the status of our reality? Does it matter if you are a butterfly or a person, as long as you are happy?

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DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Finding order in chaos: Exploring quantum systems

BY ABIGAILPOTTER, PHYSICS & PHILOSOPHY, 2021

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Humans love order. We have a natural ability to see patterns in everything around us. It's how we gather data and draw conclusions. Think about the work you do in school; you read history to see how it repeats itself, and you redo experiments to find repetition in the results. We even teach young children pattern identification with games where they match shapes with holes. We spend our lives trying to figure out how to find order in chaos. For this reason, things that do not have a recognizable pattern disturb us.

Quantum systems are a prime example of chaos because they seem to work almost randomly. For example, imagine leaving a glass of ice water on the table and returning to a glass of nearly melted cubes one minute and a completely frozen glass the next. In a classical system, that ice water would only become room-temperature water. In a quantum system, the water can reach a variety of states depending on its own initial freezing temperature, not the warm temperature of the room. For a long time, there was no explanation for this behavior. However, Nicolò Defenu, a postdoctoral researcher at the ETH Zürich Institute for Theoretical Physics, has uncovered part of the mystery.

> "Whereas a glass of ice water in a room would eventually become a glass of room-temperature water as it reaches equilibrium, long-range quantum systems are less likely to achieve such balance."

It has long been known that long-range systems, systems where individual particles don't just interact with their neighbors but particles far away, cannot be described with the classical thermodynamic limit procedure. Whereas a glass of ice water in a room would eventually become a glass of room-temperature water as it reaches equilibrium, long-range quantum systems are less likely to achieve such balance. Instead, they reach metastable states, where the system relaxes into a long-lived state of energetic quasi-equilibrium. The metastable particle has an energy level higher than the lowest possible energy level, known as the stable ground state, but maintains a long lifetime, similar to equilibrium at the ground state. However, the metastable state is unstable; any disturbance will likely cause the particle to change energy levels. Similar to how you can balance a tower of cards, it will fall apart at the slightest disturbance.

Experts associate metastable states with Heisenberg's uncertainty principle, which establishes the inability to know the exact location and momentum of a particle based on initial conditions. However, experts can predict the probability of each potential location using probability distributions based on the energy level of the particle. In fact, the number of stable energy states of a quantum system corresponds to the number of degrees of freedom — the number of independent variables that define a particle's state — and thus to the number of potential locations of a particle in a long-range system.

Previously, the widely accepted theory stated that particles have an infinite number of probabilities. Ergo, particles have an infinite number of possible locations, which makes their return to their initial state unlikely. Because the infinite combinations of probable locations lack distinction, experts defined the energy state of a quantum particle as all possible states on an indiscrete spectrum. However, after reducing the problem into one dimension, Defenu calculated how different particles oscillating positions interacted. These interactions between oscillating systems, known as couplings, remained discrete, meaning that what was originally thought to be a spectrum remains distinct. As such, Defenu displayed that each of the states in which a particle can be actually remains discrete, meaning that the particles are more likely to return to their distinct initial positions while changing locations.

This realization helps us to understand how metastable states actually work. Additionally, it means that, up to the thermodynamic limit, long-range systems present finite recurrence times. This is directly connected to the Poincaré recurrence theorem, which states that some discrete state dynamic systems, such as long-range systems, will eventually return to their initial state after a finite period.

With this understanding of quantum probabilities and equilibrium, we can improve quantum computing and simulations. We may be one step closer to discovering order in something that was thought to be chaos.

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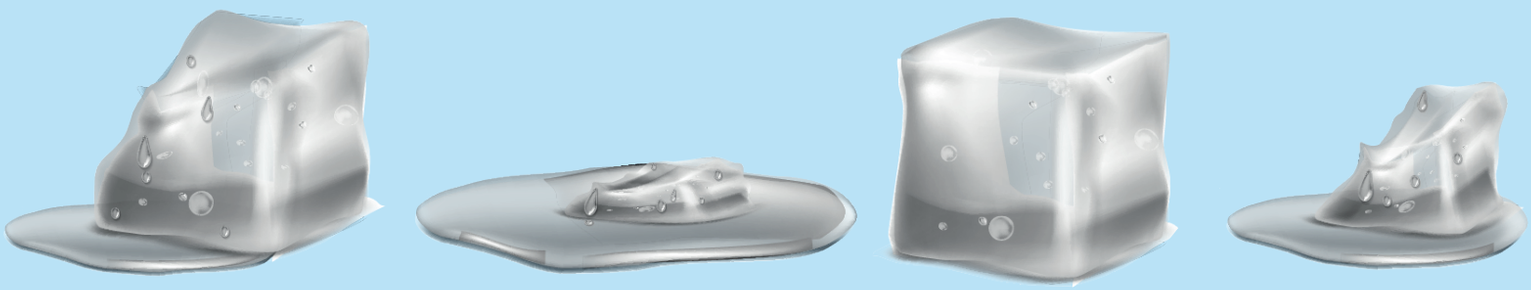

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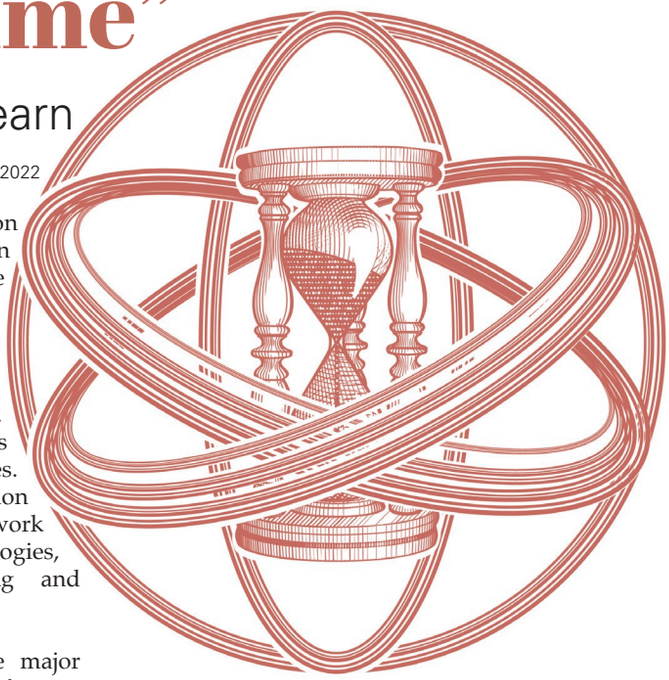
Why quantum mechanics isn't a "waste of time"

How quantum clocks have more to learn

BY KYLE KIRSHEN, CHEMISTRY, 2025 DESIGN BY KATIE GREEN, BIOENGINEERING, 2022



What exactly is time? This central question has stumped physicists for years because it seems to transcend definition. Albert Einstein helped bridge the gap with the realization that time is only considered measurable because a clock does so. In theory, that makes perfect sense. Humans created clocks to designate measurements of time for everyday life, a figment of manipulation and self-characterization. In actuality, time is not a single universally measured quantity, but rather a fluctuating mechanism solely based on what clock is used to define it. Thus, physicists thought they could build on that concept in the realm of quantum mechanics.

Einstein proposed differing views of how physics should be used in the real world, leading to how quantum theory has changed the understanding of time. It led to the understanding that time can be defined by quantum systems, serving as clocks. Dubbed 'quantum clocks,' they are the most optimal type of atomic clock and are far superior to conventional clocks. The first and only was created in 2010 by the National Institute of Standards and Technology and was found to be the most precise atomic clock in the world, capable of demonstrating many concepts from Einstein's theories of relativity.

Quantum clocks specifically illustrate special relativity, which says that the faster something travels the slower time appears to pass, just another example of how time can be manipulated with other objects. This is the idea behind Einstein's twin experiment in which one twin travels at light speed while the other remains stationary. The twin moving at the speed of light comes back having aged less than the other, creating time dilation. This idea can be applied to atoms in superposition to create a quantum clock.

Superposition is a phenomenon where an object can simultaneously be in multiple states until observed. It is a complicated theory because the moment an object in superposition is observed, it is only found in one state. Before observation, it exists as a function of probabilities. Though perplexing, superposition continues to base the framework for quantum technologies, making quantum computing and communication possible.

Superposition also serves the major basis of several theories like the famous Schrödinger's Cat thought experiment. The experiment says that a cat in a box with bottled poisonous gas and a radioactive substance will be between a point of life and death at the same time. This is due to the superposition of the nucleus being between a state of decay and non-decay before observation. It introduces the fact that atoms, particularly radioactive atoms, define their passage of time through radioactive decay. This type of decay is quantized and cannot be concretely predicted. Sure, for some elements like radioactive carbon there is an averaged and measured half-life, the time for half of a sample to decay. However, that is just an average of what half-life decay looks like. There are outliers to that trend, and it makes it difficult to say when exactly an atom will break down.

Radioactive atoms are ideal quantum clocks because of the way superposition allows them to be in multiple states, decayed and whole, at the same time until a disturbance collapses the system into decayed or whole. The passage of time is not experienced as seconds moving on a clock. Rather, the nuclei of both an undecayed atom and a decaying atom would look identical until the moment of collapse. Radioactive atoms do not define their passage of time through measurement but in the moment of observation.

These atoms could experience time dilation, leading to a form of time measurement in quantum clocks. If one of the superposed states was in motion while the other remained still, they would not just be between states of decay and non-decay, but the atoms would exist at different ages, one older than the other. This would demonstrate the twin experiment within a single atom, unlike anything ever exhibited, and will most definitely play a bigger role in quantum clocks going forward.

While highly nuanced, this type of thinking, especially involving time dilation, can affect the evaluation of time and the sophisticated design of higher precision quantum clocks. Yes, this mess of parts provides more questions than answers, specifically how to bring this idea to life and what the effects will be, but hopefully those answers will be solidified through testing and enforce time as one of the most fascinating glitches in the universe.

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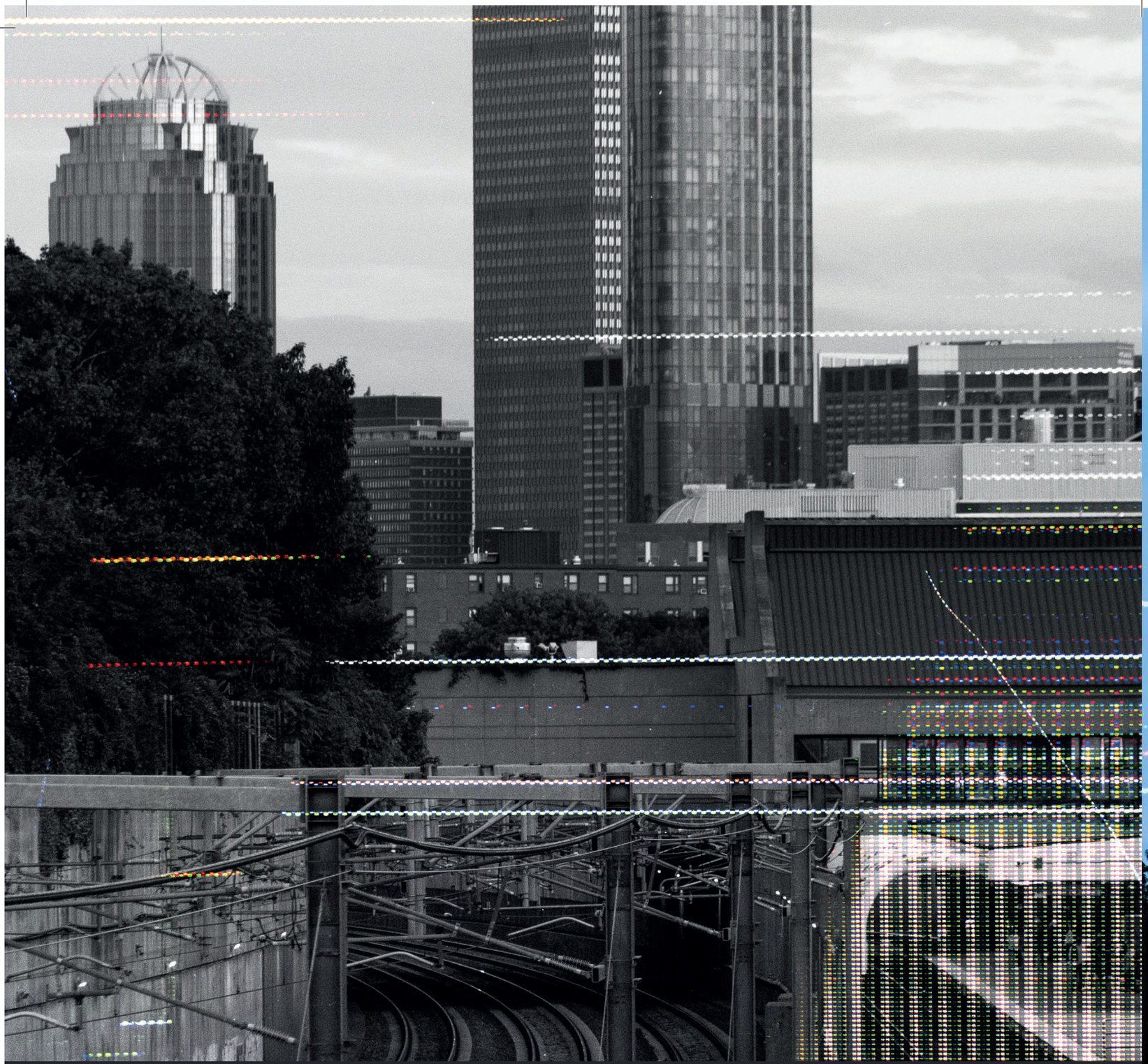

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