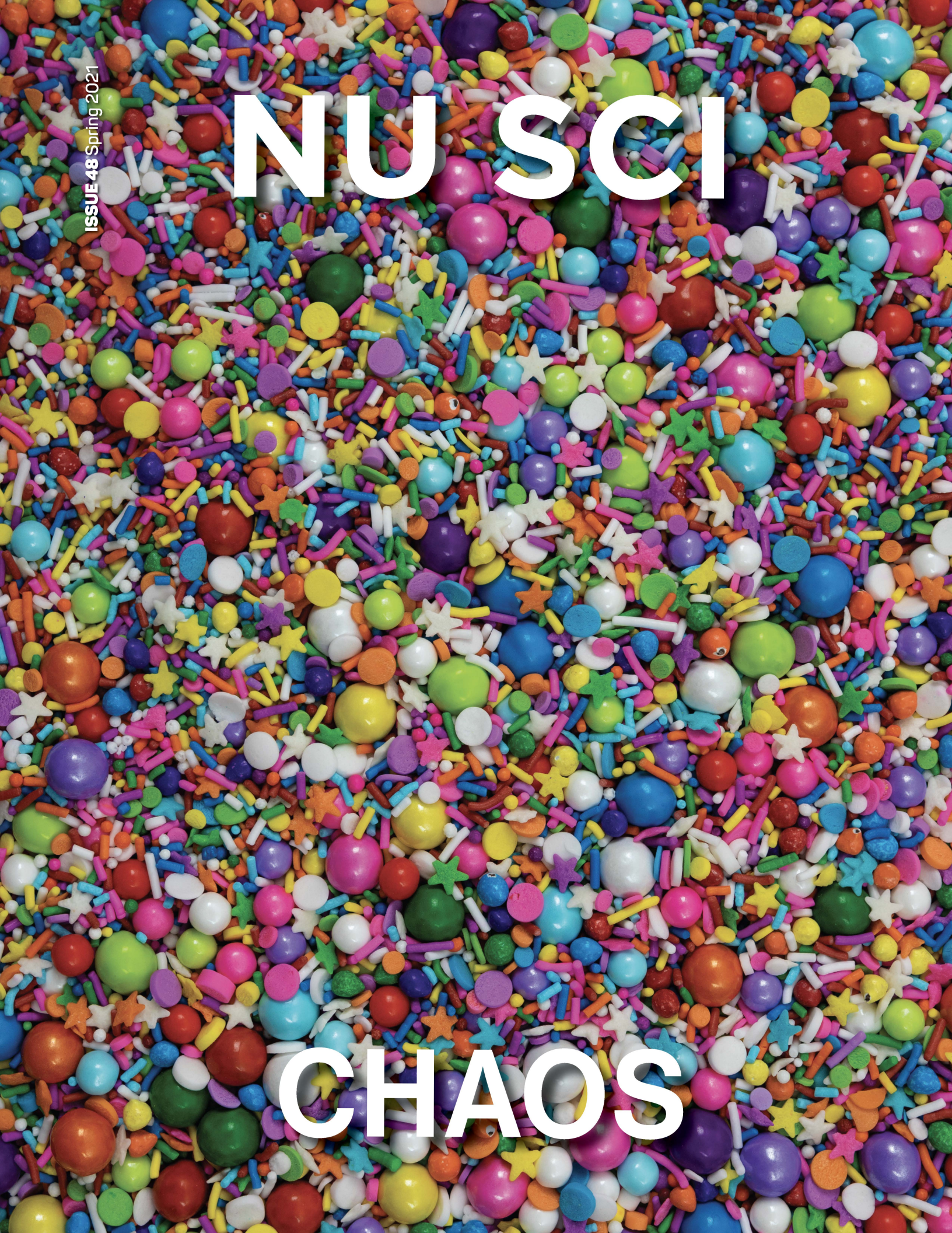

# NU SCI

ISSUE 48 Spring 2021

# CHAOS

Spring 2021

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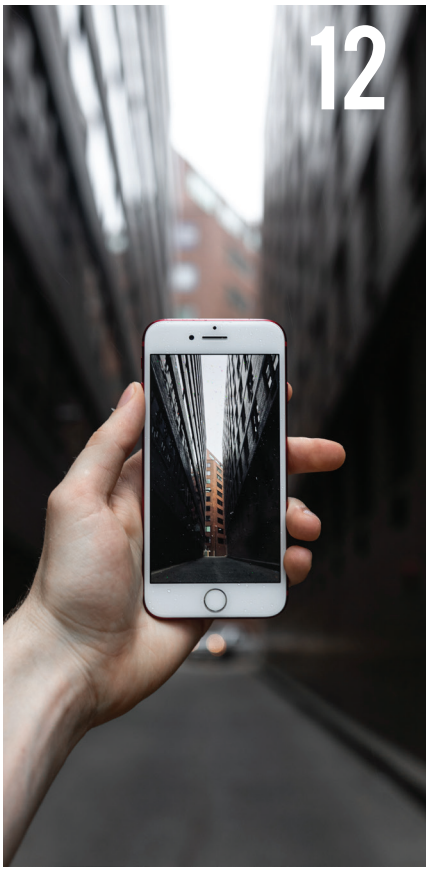


# LETTER FROM THE EDITOR

It's been a little over a year since we had to suddenly vacate campus and start online classes and co-ops. The last-minute scuffle to arrange travel plans, store our belongings, and say goodbye to friends can only be described as utterly chaotic. Preparing for a nationwide lockdown was chaotic. Working in essential professions was, and is, chaotic. The present is still chaotic, and the foreseeable future seems like it will be that way too.

We know all too well that chaotic times can be overwhelming and are often associated with crisis. This dangerous combination can induce a great deal of anxiety — how can we be sure everything will be okay? In our everyday lives, we have the perception that most things are under our control, or someone else's. And that keeps us calm.

Yet how often do we fail to notice that chaos is all around us and is, in fact, necessary for life? The stochastic processes that enable the universe to exist, created the conditions for life on Earth, and painted our night sky with astral murals all emblemize the beauty that comes from chaos.

Before the pandemic, I had my whole life planned out — my future classes, potential graduate schools, types of dogs I'd adopt. Now, I've learned to revel in the chaos. A year ago, I couldn't have predicted where I am today, and I don't have a clue where I'll be in another year. And that's okay. But tonight, I'll finish typing this up, make dinner, and spend time with my hedgehog, Maple Toast. Then, I'll go to sleep. Tomorrow? I don't know what I'll do, but I'll make the promise to embrace the day's infinite possibilities and maybe look up at the astral murals that the chaos in space so diligently painted for us all those eons ago. Chaos is only natural, so I'd like to breathe in the good parts of it before it's too late.

Of course, we love order; there's no denying that. Humans love predictability, consistency, stability, and security. There's beauty in that too. In the spirit of order, our members have organized their brilliant ideas, designs, and photographs into this issue. One constant in this absolutely chaotic year has been *NU Sci* producing another phenomenal set of magazines thanks to our equally phenomenal members!

While this year hasn't been predictable or secure, I hope you'll start to see every shade of harmony and strife within "Chaos."

Binh Dang
Editor-in-Chief

# STAFF



Cover Photos by Gus Mueller

# **I'll sleep when I'm dead:** The curious case of fatal familial insomnia

BY YASMINE MYFTIJA, BIOLOGY, 2021
DESIGN BY SOPHIE PATE, ARCHITECTURE & DESIGN, 2024

**Can you imagine never sleeping again?** We often underestimate the importance of sleep; by some estimates, college students in America get an average of 6 hours of sleep per night, as opposed to the suggested 8–10 hours. Getting enough sleep is extremely important — it gives the brain time to consolidate memories and new information, and leaves you well-rested in the morning. However, for the rare few suffering from fatal familial insomnia, the progressive loss of sleep can lead to a painful and tragic end.

According to the National Organization for Rare Disorders (NORD), fatal familial insomnia is designated as an extremely rare genetic disorder, affecting approximately one in a million people each year. According to the NIH, after symptoms begin to show, fatal familial insomnia leads to death in about 6–36 months. As of right now, only 70 families are known to have the disorder.

Fatal familial insomnia is a prion disease, meaning that its cause can be linked to an unusual variant of the prion-related protein gene, abbreviated as *PRPN*. The variant version of this protein makes the affected individual's body produce misfolded versions of the human prion protein and accumulate in the brain over time. While it is possible for a spontaneous mutation in the *PRPN* gene to occur and cause fatal familial insomnia in an individual with no family history of the disorder, most cases are inherited from one's own parents. Specifically, fatal familial insomnia follows an autosomal dominant inheritance pattern, meaning that only one parent needs to have the disorder for there to be a high likelihood that it will be passed down to their children. A diagnosis of this disorder can be verified by genetic testing for mutations in the *PRPN* gene, or through other clinical testing such as positron emission tomography (PET) scans, which can detect abnormalities in the brain related to the disorder's presentation.

Misfolded prion proteins are known to be quite toxic, and as they accumulate — specifically, in the thalamus of the brain, a region whose main function in the relay of signals (sensory or motor) and the regulation of alertness and conscious thought — are accompanied by a plethora of detrimental symptoms. The condition has a long incubation period as the body makes these misfolded prions, but once levels of such prions hit a critical level, the clinical presentation of the disease is quite short. Fatal familial insomnia is a neurodegenerative disease, which as the name suggests, is characterized by progressive insomnia which worsens over time caused by damage to and the death of neurons in the brain.

People affected by the disorder may initially have mild symptoms, such as issues with concentration, speech problems, confusion, or inattention. Some will also exhibit abnormal movement of the eyes, double vision, swallowing problems, muscle spasms or tremors, or other symptoms which are similar to Parkinson's disease. As time goes on, the autonomic nervous system may be affected as well, leading to varying symptoms including but not limited to hypertension, tachycardia, and fevers. These symptoms may also be accompanied by depression or anxiety. Ultimately, people affected by fatal familial insomnia fall into a coma and, as the name suggests, will eventually die.

As of right now, there is no cure for fatal familial insomnia. While this is certainly a grim outlook for the few affected by the disorder, some treatment options do exist. Treatment is currently aimed at managing the specific symptoms which vary in each patient, a comprehensive process which involves the joint efforts of neurology and psychology teams. For example, if a patient begins having seizures, they may be prescribed anti-epileptic medications. Similarly, if they are exhibiting muscle spasms, known clinically as myoclonus, they may be treated with clonazepam, a sedative which relaxes the spasming muscles. Patients with fatal familial insomnia may also be advised to stop taking any medications with memory-related side effects, or those which unintendedly may worsen insomnia. Due to the heritable nature of the condition, family genetic counseling and the implementation of psychological support systems is recommended as well.

PHOTO BY SHUTTERSTOCK

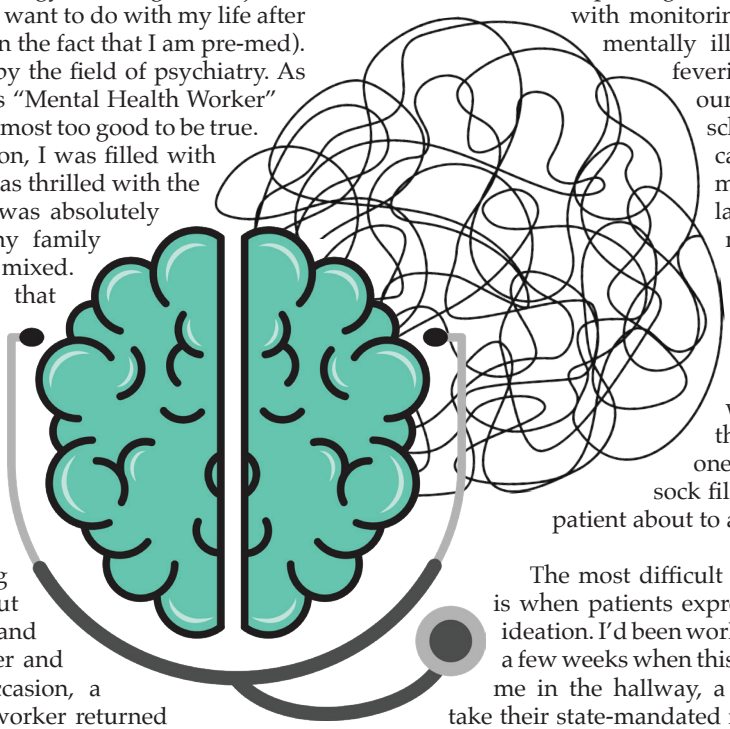
# The chaos of modern-day mental health work

BY LILY WEBER, BIOLOGY & ENGLISH, 2023

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

**My interview at Arbour HRI Hospital was unlike any I'd experienced before.** Among the typical questions about my resume or past healthcare experience were questions about how I felt about restraining people physically, or what I'd do if I walked into a patient's room and found them engaging in self harm. Perhaps those sort of questions should be expected when applying to work for a mental hospital, but it was startling to be confronted with them so directly. After working at the hospital for nearly three months, these are questions I still find myself asking.

As a member of the niche Biology and English major, I'm constantly asked about what I want to do with my life after college (at which point I add in the fact that I am pre-med). I'm currently very intrigued by the field of psychiatry. As such, when I encountered this "Mental Health Worker" position on NUWorks, it felt almost too good to be true. After being offered the position, I was filled with mixed emotions. Part of me was thrilled with the opportunity, but part of me was absolutely terrified. The reactions of my family and friends were similarly mixed. Beyond the safety concerns that come with jobs in healthcare, the stigma surrounding mental illness and the people it affects are deeply rooted in society.



When I arrived in Boston for my orientation, my emotions were only heightened further. Between heartwarming anecdotes from staff about moments of connection and healing were stories of danger and fear. On one memorable occasion, a nurse recounted how her coworker returned to work with a black eye after being assaulted by a patient.

While managing my emotions concerning our training, my head was pumped full of information about working there. Throughout our two-week orientation, I was inundated with various procedures — from more menial tasks like charting and admissions to more sobering lessons on verbal de-escalation, trauma-informed care, and physical restraint. Afterward, we completed five "shadow shifts" where we followed around various mental health workers as they completed their shifts. On my first shadow shift, the worker I was observing said "If you can work here, you can work anywhere." I was hardly cognizant of just how right she was. I found myself asking what kind of job was so brutal and arduous that it could prepare you for anything?

Answer: this one. The schedule for each day is essentially the same: get report from the previous shift, do safety checks (methodically going through the unit and confirming each patient's safety every 15 minutes), escort the patients to breakfast, take patients for fresh air, conduct a community meeting with the unit, take the patients to lunch, another fresh air break, and then give report to the oncoming staff. As regimented as it seems, it hardly ever proceeds as such. It can be hard to keep things timely when you're tasked with monitoring the care of 17 acutely mentally ill individuals. While we feverishly glance between our watches and the huge schedule on the wall, fights can break out, and patients may start screaming, laughing, or crying. They may begin walking through the hallways in various states of undress. The highs and lows of the job are mind-blowing. I can be sitting with a patient watching them play video games one moment and grabbing a sock filled with batteries from a patient about to attack staff the next.

The most difficult situation of all, perhaps, is when patients express suicidal or self-harm ideation. I'd been working for hardly more than a few weeks when this happened to me. Behind me in the hallway, a patient was refusing to take their state-mandated medications. They began screaming and threatening staff. As I entered another patient's room, they expressed that they were triggered by the situation and wanted to self harm. At that moment, I suddenly felt very young. How was I, a 19-year-old kid barely halfway through college, supposed to offer wisdom or comfort to someone many years older, whose pain and suffering I could hardly fathom? The answer, I think, lies in one very basic fact: We are all human beings. Whenever I get overwhelmed at work, I try to remember that. Human beings crave connection, empathy, and a genuine effort on someone's part to listen. These skills don't require a special certification or years of mental health experience. They are something we either have or don't. If I've learned anything from my co-op experience so far, it's that.

PHOTOS BY SHUTTERSTOCK

# On psychedelics: The chaotic mind

BY SARA GANNON, BEHAVIORAL NEUROSCIENCE, 2021

DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

**Common psychedelics such as mushrooms and LSD are often revered for their hallucinogenic properties and the way they alter one's perceptual experience**, but what really is going on behind the scenes to generate this shift in consciousness? What is changing within the brain? Scientists ultimately attribute it to one thing: chaos.

Psychedelics generate changes in sensation and perception by changing how neuronal circuits in the brain function. After ingestion, the drug molecules enter the bloodstream through the digestive system, then cross into the brain. Once inside of the brain, these drugs cause temporary chemical imbalances that lead to changes in the wiring of neurons in the brain, ultimately producing the sought-after experiences of euphoria, warped perception, and even hallucinations.

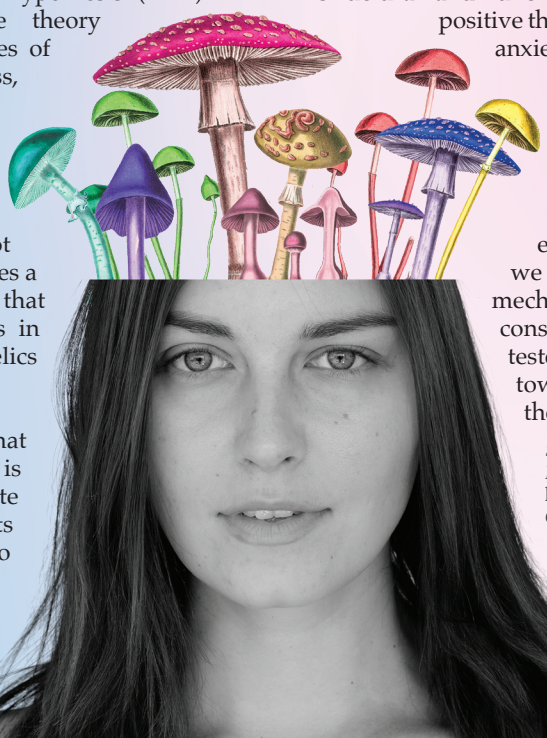
Within the brain, there are networks of millions, billions, and trillions of neurons that communicate with each other and regularly produce everything we experience including sensations, perceptions, thoughts, and actions. Under the influence of a psychedelic, the resulting chemical imbalance within the brain leads to dysregulation of these networks and an increase in the diversity of the signals they use during communication. This means that neurons are communicating with neurons they don't normally communicate with, or increasing or decreasing the levels of communication with previously-established networks. The increase in signal diversity is, in essence, an increase of entropy in the brain. This neural entropy is characteristic of psychedelic experiences and has been found experimentally to be the driver of the most well-known effects of psychedelics, such as altered subjective experiences and mood and personality changes.

In 2014, Dr. Carhart-Harris and colleagues published a theory coined the Entropic Brain Hypothesis (EBH) detailing this phenomenon. The theory proposes that there exists two states of consciousness: primary consciousness, with uninhibited cognition and organized brain network function, and secondary consciousness, characterized by inhibited cognition and higher entropy of neuronal activity. This theory maintains not only that neuronal entropy determines a person's state of consciousness, but that subjective experiences and changes in perception characteristic of psychedelics are directly related to this entropy.

In addition to the determination that increased entropy in neural activity is the main mechanism mediating acute alterations in consciousness, scientists now believe that the entropy may also mediate longer term changes in the brain. Evidence suggests that there are structural changes occurring between neurons during psychedelic drug use that disrupt neuronal circuitry in a semi-permanent way.

Invoking entropy of neuronal communication can cause existing neuronal connections to be strengthened and even stimulate the generation of new connections. Psychedelics such as LSD and psilocybin, or mushrooms, have been found to be associated with new growths of neuronal neurites, spines, and synapses — all structural elements of the cell that facilitate communication. These new growths lead to more connections between neurons whether they were previously connected or not. Thus, structural changes facilitated during periods of psychedelic use are not simply temporary alterations in consciousness, but can lead to lasting effects on sensation, perception, and cognition.

The next logical question to ask is "can these long-lasting changes serve a therapeutic purpose?" The answer from the scientific community is a resounding yes. Historically, ketamine has proven this approach worthwhile; though primarily categorized as an anesthetic, ketamine and its psychedelic-like properties have proven successful as an antidepressant due to its ability to encourage the formation of new synapses — the most fundamental unit of neuronal communication — in areas of the brain responsible for emotional regulation which are often dysfunctional in depressive patients. This structural change in the brain of patients leads to subsequent functional changes that essentially serve to "rewire" the brain. Some functional changes observed experimentally thus far include increased focus, emotional balance, and an increase in meaningful psychological insights about oneself or the world in general. Furthermore, it has been suggested that common psychedelics such as LSD and psilocybin can have similar effects to ketamine by stimulating structural and functional changes in the brain that lead to positive therapeutic outcomes in cases of depression, anxiety, and related disorders.



These novel psychedelic therapeutic approaches look promising already and there is even more to look forward to in the future. Thus far, the cellular and molecular mechanisms of psychedelic experiences have been characterized, but we have yet to understand the whole-brain mechanisms that drive these changes in states of consciousness. As new models are developed, tested, and debated, we can work diligently toward a more thorough understanding of the brain and our own experiences.

*Scientific Reports* (2020). DOI: 10.1038/s41598-020-74060-6
*Frontiers in Human Neuroscience* (2014). DOI: 10.3389/fnhum.2014.00020
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PHOTO BY RAWPIXEL

# WHEN SOCIAL MEDIA BECOMES SOCIAL REALITY

## How network use may predict mental health

BY EMMA TUSUZIAN, PSYCHOLOGY, 2023
DESIGN BY ETHAN WAPLE, BIOLOGY & DATA SCIENCE, 2023

**Despite the seemingly inconsequential nature of information behind a screen,** the ubiquity of social media allows it to seep into the reality of many adolescents. The culture of likes, comments, shares, and followers is widely known to seem superficial, but it has a very real connection with the mental health of developing minds. The ways in which many interact with these platforms — such as reacting to constant social feedback, developing new behaviors, and extending social anxieties — may be heavily reflected in the mental health of users or act as predictors for mental health treatment outcomes. With social media birthing a new era of atypical human interaction that blurs virtual and real-life connections, it is becoming especially important to observe its impact on the mind and brain to help explain, predict, and prevent the mental health problems exacerbated by it.

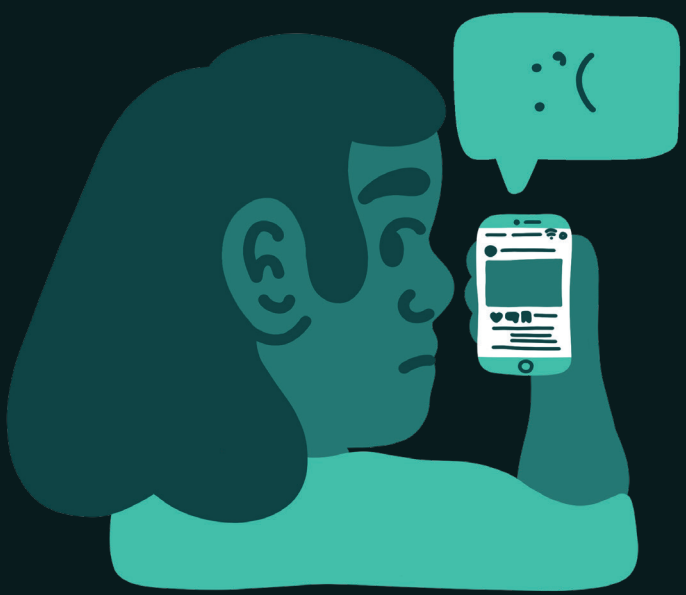
Neural changes are significant markers of adolescent development and can help understand the ways in which social media is influencing emerging generations. However, social media's effects on brain regions involved in socializing are largely unknown. A 2018 review of developmental sensitivities related to adolescents' media use reveals how neuroscience may help understand the influence of media on their well-being and opinion formation. Brain studies in the review suggest adolescents are highly sensitive to acceptance and rejection through social media. Researchers have observed increased activity in the orbitofrontal cortex and insula after participants experienced exclusion, potentially signaling heightened arousal and negative mood. These brain regions are associated with functions such as processing conflict and negative emotions, which may help explain this correlation.

The dorsal anterior cingulate cortex (dACC) has similar functions, particularly connected to processing norm violations. Stronger activity in the dACC has been seen in adolescents and young adults with a history of social exclusion, maltreatment, or insecure attachment. By comparison, spending more time with friends has a reduced response in the dACC. Studying regions and pathways involved in protective factors from such negative effects of social media may inform healing for a generation heavily influenced by social exclusion, especially for exacerbating social anxiety, depression, or other mental health problems.

With the complexity of such mental health problems stretching beyond brain activity, it is also important to consider other factors involved in social media influence on adolescents. This is particularly significant in observing symptom change in mental health problems. A 2019 review of 13 studies examined the influence of social media on depression, anxiety, and psychological distress in adolescents. It found that prominent risk factors for these mental health problems included time spent on social media, activities such as repeatedly checking for messages, personal investment, and addictive or problematic use. Specific behaviors such as social comparison, active or passive use of social media, and motives for social media use may have a greater influence on the symptoms of depression, anxiety, and psychological distress than the frequency of social media use or quantity of online friends.

There have also been recent studies on "phubbing." The term is derived from the words "phone" and "snubbing," referring to checking a smartphone during a real-life conversation and escaping from interpersonal communication. It has been seen to be correlated with forms of "FOMO," or the fear of missing out, and is defined as "a pervasive apprehension that others might be having regarding experiences from which one is absent." A study on neuroticism, "trait fear of missing out," and phubbing revealed that two forms of FOMO and problematic Instagram use were highly correlated with phubbing. Retaining a trait fear that others find more reward online as well as fearing falling behind on social media updates can be indicators of potential future mental health impacts. Patterns of how information is processed and the behaviors that follow may be more important than frequency of social media consumption.

Though these studies only establish correlational, they point research in the direction of protecting adolescents against the negative influence of online rejection or against equipping them for a healthier relationship with social media feedback. Tracking specific behaviors, attitudes, and brain processes within adolescents can help predict the onset of symptoms of greater mental health problems, potentially curbing the harmful effects of social media or even social interaction as a whole.



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*International Journal of Mental Health and Addiction* (2020). DOI: 10.1007/s11469-018-9959-8
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*Scientific Reports* (2013). DOI: 10.1038/srep02027

# HARMONIZING YOUR THOUGHTS

## Cognitive dissonance and how to relieve it

BY AMANDA BELL, DATA SCIENCE & BIOLOGY, 2023

DESIGN BY KAI GRAVEL-PUCILLO, ENVIRONMENTAL SCIENCE, 2022

**The time is 4:59 pm.** It's nearly the end of the business day and still no emails. You've been waiting to hear back from that company you interviewed with two weeks ago for a position you were certain you would be offered. 5:00 pm hits and an email arrives, but to your surprise, it's a rejection for the position you thought you were perfectly qualified for. Discomfort sets in because you had this belief that you were a skilled individual capable of earning this position, yet you weren't offered the position and this conflicts with that belief. Psychologists call the discomfort created by this conflicting belief and experience cognitive dissonance. Now maybe you claim the company wouldn't be that great to work for or you blame the interviewer for not asking the right questions. Perhaps you decide to spend more time preparing for future job interviews. In any case, your goal is to eliminate the discomfort that you are experiencing.

The belief or experience causing cognitive dissonance is a threat to one's self-image because it clashes with one of their deeply held beliefs or something that they believe strongly about themselves. According to Dr. Claude Steele's self-affirmation theory, when people experience a threat to their self-image, there are three things they will do to restore it. One option is to accept the threat and change their behavior or beliefs to eliminate the inconsistency. For example, in the job situation, someone could practice more for interviews and start receiving job offers. Another option is to adapt one's view of the threat by diminishing its importance or framing it in a more positive light. Someone could decide that the job wasn't that important or view the rejection as a learning opportunity. Lastly, Steele's theory suggests that people can reflect on unrelated but important aspects of themselves. If the job involved working in a laboratory, someone could divert their focus to their musical talent or their political beliefs if either of those are important to them.

While all of these are valid ways to deal with cognitive dissonance, some of them can be harmful to oneself and others if these methods prevent one from learning. One of the best examples of this has occurred in the medical field. Until about the mid-19th century, clinicians didn't wash their hands when dealing with different patients which resulted in rapid disease spread in hospitals. According to a review in *The Cross-Cutting Edge*, Dr. Ignaz Semmelweis was the first to impose mandatory hand washing in his ward, and as a result, disease spread dropped significantly. The problem was that other clinicians refused to take handwashing seriously because doing so would suggest that they were responsible for the loss of thousands of patients' lives. If people had continued to dismiss handwashing to maintain their self-image, they would not only prevent themselves from learning but also continue putting thousands of lives at risk. If one doesn't want to hurt themself and others, then how should one deal with cognitive dissonance?

According to a paper published in 2006 by David Sherman and Geoffrey Cohen, the best way to handle cognitive dissonance is reducing the need to distort incoming, threatening information. Dr. Steele's self-affirmation theory indicates that by self-affirming, participating in, or reporting on an important value in our lives, people become more open to information that clashes with their current views. For instance, another study by Sherman and Cohen published in 2002 found that when people with strongly-held beliefs regarding capital punishment read an article about capital punishment, those that self-affirmed prior to reading the article were able "to evaluate the information in a less biased and defensive manner." In other words, when people recognize other important parts of themselves, their self-worth stops depending on that one immediate threat, so that they can more openly handle it.

Now back to that job rejection. There's no denying that you didn't get the offer you thought you would get, but that doesn't mean you're not a smart, capable individual worthy of receiving a job offer in the future. Ultimately, by recognizing your other strengths and values, you can more easily accept threatening experiences and information that can enable self-growth.

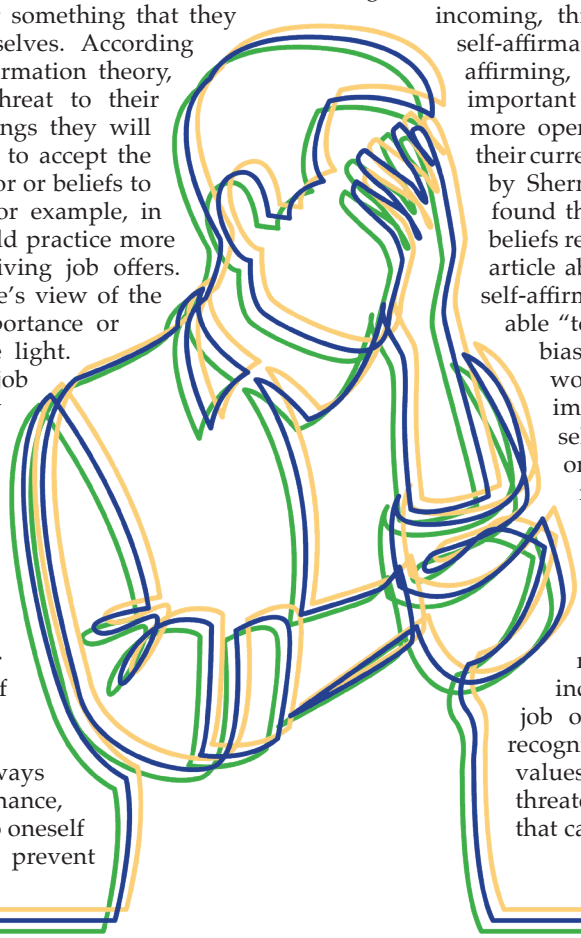


PHOTO BY SHUTTERSTOCK

*The Cross-Cutting Edge* (2019). DOI: 10.1111/medu.13938
*Advances in Experimental Social Psychology* (2006). DOI: 10.1016/S0065-2601(06)38004-5
*Current Directions in Psychological Science* (2002). DOI: 10.1111/1467-8721.00182

# MAKING MAYHEM INTO DREAMS

BY BEIYU (PAM) LIN, BIOLOGY, 2021

**Perhaps the most well-known theory of dreaming is Sigmund Freud's;** he believed that dreams were a look into our subconscious and served as a valuable tool to better understand the human psyche. Despite the domination of Freud's ideas in most psychology courses, researchers remain divided on what exactly causes dreams — particularly whether or not they are a result of random brain activity or have a deeper meaning. In 1993, Kahn and Hobson proposed an idea called the self-organization theory of dreaming, a concept that dreams are simply a byproduct of the brain organizing itself during the rapid eye movement cycle of sleep.

To better grasp this theory, the first concept to understand is the human sleep cycle. There are two basic types of sleep: rapid eye movement (REM) and non-rapid eye movement (NREM). People alternate between REM and NREM sleep multiple times a night, with NREM leading first and REM starting approximately 90 minutes after the individual falls asleep. As characterized by its name, REM sleep involves quick movement of the eyes behind closed lids. It's critical to understand, because it's believed to be the cycle in which dreams are more likely to occur. The occurrence of these dreams is possibly a result of increased activity in parts of the brain that are active during REM, such as those involved in motor, visual, emotional and autobiographical activity, but decreased activity in regions that regulate rationality.

The self-organization theory posits that during REM sleep, neuron signals are fired in a complex manner throughout the brain, which self-organizes to form a somewhat linear narrative. The belief is that a level of "consciousness" can emerge from a complex cerebral pattern network that's created from activated memories. In simpler terms, it's the human brain's way of taking memories that arise during sleep and structuring them into a way that makes sense, thereby creating a dream. Oftentimes, the brain is in a state of weak control while dreaming, which includes changes in neural activity and lack of external stimuli, making it more prone to focus on activated memories and organize them into a "story." One limitation of the brain in this capacity is that it can't control which specific memories arise during sleep, potentially leading to chaotic and nonsensical dreams.

While self-organization is less researched than other theories of dreaming, it has its unique strengths that serve as the foundation for its ideas. For example, it offers a potential explanation for why dreams are often quickly forgotten. Because of the weak control that the brain has during self-organization dreaming, the story is just a temporary combination of memories. When the individual wakes up and the brain is once again well-controlled, it's much easier to forget what happened in the less-controlled state. In addition, the theory also provides a possible reason for the nonlinear or discontinuous aspects of dreams. Since the brain is combining fragments of memories, it's likely that these fragments won't be perfectly connected to form a completely coherent story.

Dream theories go beyond just Freud and self-organization. Rosalind Cartwright's threat simulation theory views dreams as a biological defense mechanism, in which people can simulate threatening events multiple times and use the repeated scenarios to their evolutionary advantage. On the other hand, the expectation-fulfillment theory postulates that when people can't fully express their emotional arousals throughout the day, they discharge what didn't come out at night through dreams. There are a number of other dream theories outside of these, including activation-synthesis and Carl Jung's theory of dreams as direct mental expressions. With many ideas circulating about how dreams formulate and what they mean, it's likely that these theories are not mutually exclusive and multiple theories overlap in the truth. As research continues to be funded and more ideas come to light, it'll be fascinating to see which theory will come to dominate.

*Frontiers in Psychology* (2018). DOI: 10.3389/fpsyg.2018.01553
*Frontiers in Psychology* (2016). DOI: 10.3389/fpsyg.2016.00332
*Frontiers in Psychology* (2013). DOI: 10.3389/fpsyg.2013.00408

DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022
PHOTO BY SHUTTERSTOCK

# REVELING IN CHAOS

BY KRISTINA KLOSOWSKI, BEHAVIORAL NEUROSCIENCE, 2022
PHOTO BY MUHAMMAD ELARBI, COMPUTER SCIENCE, 2022

**A lot of us have people in our lives who seem to experience one chaotic situation or crisis after the next.** After a while, you might think that this person, on some level, enjoys the chaos and unpredictability of these situations. Indeed, it may be true that people manufacture chaos in their lives because they thrive on unpredictability. Based on different personality types, it certainly seems that some people innately value and desire change, spontaneity, drama, and unpredictability. These are all hallmark characteristics of the abstract term, "chaos." But beyond that, is it possible to actually be addicted to chaos?

According to expert consensus about the reward system in the brain, people can be addicted to almost anything, not just substances. As with drugs, many high-risk behaviors such as gambling, sex, pornography, and shopping can hijack the reward pathways in our brains to elicit those same addiction patterns and behaviors. Currently, experts can only support "chaos addiction" with anecdotal evidence. However, individuals who claim or appear to be addicted to chaos often express those same addictive and compulsive life patterns. In fact, the phenomenon of chaos addiction is common among people recovering from substance use disorders. There is speculation that this occurs when people become accustomed to the level of chaos present in their lives during an active addiction; the subsequent lack of chaos in their lives during sobriety can be anxiety inducing. In other words, frequently being placed or placing oneself in tumultuous situations may cause these situations to become one's comfort zone, therefore making the unpredictability of life the only predictable thing.

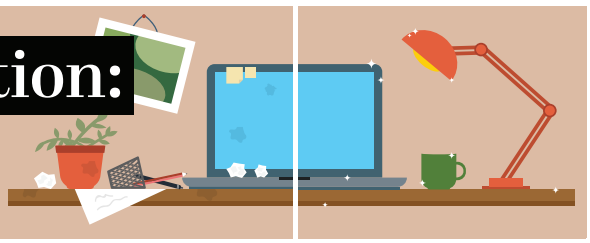
The idea of a chaos addiction also appears in other demographics, like entrepreneurs and business owners. Addiction to work, or workaholism, is a more established phenomenon within the psychological and medical communities. However, some elements of workaholism are similar to chaos addiction, including compulsive tendencies, the inability to relax, the need for action, and constantly being in a mental state of crisis management. The two phenomena could be closely related, or chaos could simply be one element of workaholism.

It is important to note that the specific theory of addiction to chaos has not been tested nor proven in scientific research and empirical studies. Given that addiction and recovery are complex and nuanced topics, delving further into research regarding chaos addiction might provide more insight into the complex thought patterns present in addiction as a whole.

*Scandinavian Journal of Psychology* (2012). DOI: 10.1111/j.1467-9450.2012.00947.x

# Cleanliness and convention:
## A curious correlation

BY LAUREN VOSO, BEHAVIORAL NEUROSCIENCE, 2023



**Everyday,** people propose the best ways to keep a clean environment: keeping your space tidy, getting rid of unnecessary clutter, organizing your life. In general, society values order and cleanliness, as this represents an efficient, productive way of living. However, evolutionarily speaking, there are advantages to both a messy and clean environment. In nature, order and disorder are both common environments and each one stimulates different mindsets, leading to different outcomes.

In 2013, researchers at the University of Minnesota, led by Dr. Kathleen Vohs, performed a study, published in the journal *Psychological Science*, to explore how this aspect of nature may apply to modern humans. In a series of experiments, participants were placed in either orderly or disorderly office environments to see how being in each of the environments affected a person's decisions and disposition.

In one experiment, as the participants left their designated room, researchers asked if they would like to donate to a charity and encouraged them to take a snack. Participants in the orderly room donated twice as much money as participants in the disorderly room and were more likely to choose a healthier snack. Researchers concluded that orderly environments may influence people to make more generous or healthy choices, corresponding with an overall value of convention. In other words, in a cleaner environment, people may choose to align themselves closer with what society traditionally views as "good."

In another experimental set-up, participants were asked to come up with ideas for a project proposal in their designated environment. When the ideas were scored by blind researchers, participants in the disorderly condition created more ideas, and specifically, more innovative ones. From this, it was determined that disorderly conditions may have a positive effect on creativity. This aligns with the findings of the first experiment, as disorder, which represents unconventional thinking, can be seen as the opposite of order, which represents convention. Unconventional thinking, and the ability to move away from tradition, is highly associated with creativity and innovation.

While this experiment was performed in a highly controlled setting, its findings can likely be applied to the outside world. Being in each type of environment, either messy or clean, prompts different approaches to our surroundings that can be beneficial in different circumstances. Nature requires a balance of order and disorder to function, so maybe we do as well.

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021
PHOTOS BY SHUTTERSTOCK

# Boogie fever

## A look at the dancing mania epidemics of the Middle Ages

BY B. PARAZIN, MATH & PHYSICS, 2023

DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

**In the autumn of 1518**, Strasbourg, a prominent trading city on the banks of the Rhine River, was alive with the sound of dancing. Musicians played day and night; a new stage was constructed across from the market; and over 400 people — all stricken by the dancing mania plaguing the city — whirled, twirled, and waltzed uncontrollably, some screaming in pain, pleading for help, or having terrible visions. At the height of the chaos, allegedly, up to 15 people died each day because of the compulsion to dance, making it the largest outbreak of the dancing plague in European history, with several smaller instances recorded in the 16th and 17th centuries but stopping around the turn of the 18th century.

Though it was the largest, the 1518 Strasbourg outbreak was far from the first. Numerous medieval sources corroborate a wave of dancing mania that ravaged western Europe in 1374 and smaller local outbreaks in 1247 and the early 15th century. The earliest purported outbreak was in Kölbigk (modern-day Saxony-Anhalt), where 18 people were cursed by a priest to dance for a year straight because of their impiety. However, there is still debate whether that story is a heavily embellished real event or simply folklore.

There are some similarities across the outbreaks. First, the dancers appeared to be in some kind of altered state, indicated by their inhuman levels of endurance, ignoring sore limbs and bloody feet, and crying about terrifying visions. Furthermore, all recorded outbreaks, save at Kölbigk, happened near the Moselle and Rhine, many times in places that had previous dance epidemics. Finally, the most common remedy was for the dancers to pray to saints associated with dancing, primarily Saint Vitus and Saint John, which for the most part worked; the Strasbourg outbreak ended after the ill were sent to pray at the shrine to Saint Vitus in the Vosges Mountains.

Most researchers say that the dancing plague was a mass sociogenic illness (a mass hysteria). Psychologically, a mass hysteria is defined by the rapid spread of the false perception of having an illness through a cohesive group where the belief stems from a nervous system disturbance with no underlying physical cause. Typically, mass sociogenic illnesses spread through social channels, with the affliction spreading to those who can see or hear those already infected; this spread is especially effective when people of lower status see those of higher status displaying symptoms.

The symptoms of any mass sociogenic illness outbreak follow the common expectations and fears of the affected community; the symptoms people display conform to cultural expectations. The citizens of Strasbourg had the recent cultural memory of past dancing outbreaks from nearby towns in the region, and with the widespread worship of Saint Vitus in the area, it explains the geographic distribution of the mania and why praying to the saints remedied the outbreaks. They believed that praying at his shrines could appease an angry Saint Vitus, who sent a dancing curse, and convince him to cure the afflicted. And for many psychosomatic illnesses, one only needs to believe a cure will work for it to do so.

*The Medieval History Journal* (2009). DOI: 10.1177/097194580901200102.
*The Lancet* (2009). DOI: 10.1016/S0140-6736(09)60386-X
*Endeavour* (2008). DOI: 10.1016/j.endeavour.2008.05.001
*The British Journal of Psychiatry* (2002). DOI: 10.1192/bjp.180.4.300

Finally, to address the scale of some outbreaks, it's important to consider some factors that increase the likelihood of experiencing psychogenic illnesses. Psychological stress, nutritional deficits in either macronutrients (calories) or micronutrients (vitamins and minerals), and seeing other people experiencing a psychogenic illness are all risk factors — all of which were common in the lives of medieval and early-modern peasants, increasing their susceptibility of experiencing a mass hysteria.

A myriad of circumstances at the time created the perfect storm for some of these outbreaks. Before 1374, a massive flood on the Rhine and Moselle ravaged whole fields of crops. Similarly, in 1517, the area around Strasbourg suffered from a massive famine, disease outbreak, and series of failed rebellions against landlords and clergy members. Furthermore, in all cases, as a psychogenic illness, when dancing mania outbreaks got bigger it made them more visible and more likely to grow. For example, the Strasbourg outbreak proliferated because, to combat the outbreak, city leaders originally prescribed more dancing, constructing a stage for the dancers, and hiring musicians to play day and night, only increasing the visibility of the dancers and thus the community spread.

Overall, with the stressors of such turbulent times, combined with the memories and sights of the dancing mania, it's no wonder that some people slipped into a panicked state and experienced one of the strangest epidemics in recorded history.

PHOTO BY PUBLIC DOMAIN

# WHEN **SMARTPHONES** MAKE US **DUMB**

BY BEN WEINTRAUB, COMPUTER SCIENCE PhD, 2024

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

**In a 2017 interview with *The Guardian*,** software engineer Loren Brichter said "smartphones are useful tools, but they're addictive. Pull-to-refresh is addictive. Twitter is addictive. These are not good things." What makes this quote significant is the knowledge that it was none other than Brichter who invented pull-to-refresh, a feature now ubiquitous among smartphone apps. It should raise alarm when a once proud father of one of the most popular software features in the world forsakes his own brain-child. But, Brichter has good reason.

For years, mounting evidence has suggested that smartphones, along with many other technologies we rely on, have increasingly costly externalities. In many cases, that cost is paid in what researchers call attentional capacity — humans only have a limited number of things they can pay attention to. When a distraction occupies some of this capacity, something else must, necessarily, be deprived. It comes as no surprise then, that people perform worse on cognitive tasks when distracted by smartphones. In fact, researchers at Xavier University found that students reliably performed on only 25–40 percent of test questions for which their phones rang during the relevant lecture content.

One of the most reproducible results in psychological research is that humans are unable to multitask. Trying to engage in a task while using a smartphone means, in practice, that the task is not really getting done. Adam Gazzaley and Larry Rosen, neuroscientist and psychologist, respectively, put it succinctly in their book "Distracted Minds: Ancient Brains in a High-Tech World", when they wrote, "our brains do not parallel process information."

In fact, the situation is even more dire. In a recent study out of UT Austin and UC San Diego, researchers showed that even the mere *presence* of a smartphone can degrade cognitive performance. In this study, participants were asked to complete tests of working memory and fluid intelligence. Half of the participants were told to leave their phones in their bags in another room. The other half was told to keep their phone on them as they normally would. The researchers found that the students who kept their phones on them performed significantly worse on the tests — even though no participants actually touched their phones during the course of the experiment. The reason for this, posited by the researchers, is that the presence of a smartphone eats up significant attentional capacity.

> "Researchers showed that even the mere presence of a smartphone can degrade cognitive performance."

At a deeper level, smartphones may be hijacking our focus via a mechanism called *automatic attention*. When stimuli are frequently associated with long-term goals, our brains may continue to respond to those stimuli, even when we are not actively thinking about the goals they relate to. One example of this is when people respond to hearing their own name, even when focused on something unrelated. This response can backfire, however, when such a stimulus is frequent in the environment but irrelevant to the task at hand. When such a situation arises, attention shifts from the task to the stimulus. When it comes to smartphones, the researchers say that they "may redirect the orientation of conscious attention away from the focal task and toward thoughts or behaviors associated with one's phone." In fact, the cognitive cost may come not just from the distraction itself but from our own effort to ignore the stimulus and continue focusing on the task at hand.

Given these disturbing developments, it should come as no surprise that there is a growing movement of tech insiders who are raging against the machine. Along with Brichter, numerous others have gone from technology developers to Cassandras, warning of impending doom. This brings to mind the Biggie Smalls lyric, alluding to the dangers of dealing in addictive drugs: never get high on your own supply.

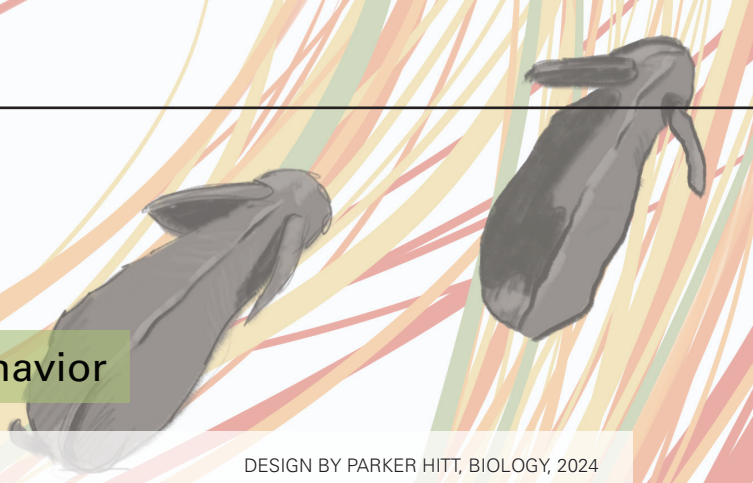
*Journal of Verbal Learning and Verbal Behavior* (1972). DOI: 10.1016/S0022-5371(72)80001-X
*Teaching of Psychology* (2009). DOI: 10.1080/00986280903425912

An empty street in Washington D.C. is echoed through the screen of a smartphone on a dreary summer afternoon.

PHOTO BY GUS MUELLER, MECHANICAL ENGINEERING, 2023

# HERD HARMONY:

## Technology to study animal group behavior



BY RACHEL LINES, BEHAVIORAL NEUROSCIENCE, 2023

DESIGN BY PARKER HITT, BIOLOGY, 2024

**What sets a group of monkeys on a mission to a new place?** What compels large schools of fish to change direction from a predator? How do flocks of geese decide to land in the Fens or pick away at the grass on Centennial? On the individual level, researchers have explored decision-making capabilities, and studies have ranged from exploring self-control in cuttlefish to the memory-based choices of elephants. But beyond the study of individual animals, researching group dynamics and collective thought processes of other species presents many logistical problems for researchers. In large animal groups, it is incredibly challenging to monitor the collective movement of so many individuals, and such data is accompanied by complicated analysis. With the introduction of new technologies and algorithms, this area of research has recently grown, allowing for tracking and monitoring of many animal movements and interactions.

As tracking systems have advanced, researchers have created many novel methods for collecting mass amounts of group behavior data. More rudimentary technologies include stationary cameras, which can capture a variety of species in a wide range of habitats but present challenges in low-density areas where animals may be less likely to cross the view of cameras. Additionally, unmanned aerial vehicles (UAVs) allow for non-disruptive behavior monitoring. Data collected from UAVs can be used to observe the movement of entire groups of animals across vast distances and for lengthy periods of time. However, UAVs meet challenges when the species of interest is too small for the camera to capture. Like with stationary cameras, habitats can also cause difficulty — UAVs can't record animals inside a dense canopy or in murky, opaque waters. Satellite imaging is another method used by scientists that can be beneficial for the study of migratory species and herds.

For more detailed tracking, including observations of behavior, body orientation, and proximity between animals, bio-loggers or animal-mounted sensors can be used. Inertial sensors, measuring speed and acceleration, can help define specific movements, such as body orientation and gaze. GPS tags can provide precise location information to observe individual interactions, leadership behaviors, or even descriptive traits about an individual. These devices are typically placed on captured animals and can be worn as collars, backpacks, or even attached via suction cup. Other bio-loggers can be internally implanted, such as passive integrated transponder tags. These devices act as lifetime barcodes and provide information when a tagged animal passes by automated tag readers and scanning systems. Finally, researchers can use data collected from the perspective of the animal itself, including animal-mounted camera footage, accelerometers that pick up body vibrations, and microphones that record vocalizations and environmental sound.

Animal behavior data can be tricky to review objectively. Researchers may hypothesize as to why a group of animals would make a certain decision, and it can be challenging to separate those expectations from recorded behaviors. Algorithms have been developed to eliminate this bias — some methods automatically model body orientation or allow time-consuming data, such as acoustic observations, to be processed quickly. Machine learning techniques allow for the automatic classification of animal behaviors without direct human observation.

This technologically aided behavioral observation has allowed researchers to collect massive amounts of animal behavior data, revealing the seemingly unpredictable and disorganized patterns and motivations for collective animal behaviors. For example, researcher Ariana Strandburg-Peshkin of Princeton University studies collective behavior and leadership distribution amongst groups and observed a baboon troop using high-resolution GPS animal tracking and habitat imaging using UAVs. Her team determined that the troop commutes to important foraging sites using roads and the individuals prefer to move into areas recently occupied by their troopmates. Emphasizing the importance of avoiding human disruption of these animal habitats, the researchers employed collective behavior technology to identify areas of importance to the troop of baboons. Given their preference for locations where other baboons had recently been, it is crucial that human activity doesn't force the baboons to move to a new location, disrupting their natural foraging and sleeping behaviors.

Through technological advances in videography and tracking, collective behavior data can now reveal important sites and movement patterns for endangered species. How is leadership distributed amongst baboon troops, and what characteristics define a leader? These questions can be answered using these tracking technologies and can reveal natural behaviors amongst similar species. Animal behavior can also provide insight on human tendencies. Humans are animals too — and we have a lot to learn from the collective behavior of other animals in our world.

*Phil. Trans. R. Soc. B* (2017). DOI: 10.1098/rstb.2017.0005
*eLIFE* (2017). DOI: 10.7554/eLife.195051

PHOTO BY HARRY STRAUSS VIA PIXABAY

# PLAN BEE: HOW HONEYBEE HIVES ADAPT TO LOSING THEIR QUEEN

BY EVAN MULLANEY, PSYCHOLOGY, 2023

DESIGN BY YECHAN YANG, BIOLOGY & PSYCHOLOGY, 2022

**At first glance,** the sounds and sights of honeybees buzzing about may seem chaotic, but there is actually quite a bit of structure to the roles that each bee plays in a hive. Worker bees do most of the grunt work like cleaning the honeycomb cells, feeding other bees, and collecting pollen. Drones are male bees whose only job is to mate and reproduce, but with whom do they reproduce? That would be the queen bee — the head of the hive. Because there is only one queen bee, when a hive has an underperforming queen or the queen is killed, they need to promptly get to work in crowning a new one.

A honeybee hive may need a new queen for a variety of reasons. Queen bees produce a pheromone, called the queen mandibular pheromone, that they share with the hive by touching, grooming, feeding, and generally interacting with other bees. The pheromone tells the hive that there is no need to build new queen cells. As a queen gets older, she produces less of the pheromone, and the hive knows that soon they will need a new queen. Sometimes the queen bee may not be too old for the hive but is sick or is generally not producing enough pheromone, indicating that she needs to be replaced. Most commonly, this replacement happens in a process called supersedure.

Supersedure begins with worker bees building small cups in the hive to lay eggs in. Once the cup has an egg, it is converted into a queen cell. A cell refers to any enclosed space made with beeswax that can store honey, pollen, or raise young bees. Unlike worker and drone cells, the queen cell is larger, and hangs downward off of the honeycomb. From their cell, queen bee larvae are fed royal jelly, a special substance that helps queen bees grow with healthy reproductive organs. After about two weeks, queen bees are fully grown and break free from their cell. During supersedure, multiple cells are prepared with queen larvae. In a dramatic and violent fashion, the first queen to leave her cell visits the other growing queens, stinging them to death while they are trapped in their cells. If there is more than one queen present in a hive at a time, they fight to the death until one queen emerges victorious.

Sometimes, honeybees need to act fast in the event that their queen is suddenly killed or removed from the hive. If this happens, a preexisting cell with a young worker bee larvae is converted into an emergency queen cell. The larvae is fed royal jelly and eventually grows into a queen. Because the cell was originally built horizontally into the honeycomb for a worker bee and is not large enough for a queen, the cell is extended with an outward and downward bend to accommodate for the new queen's size.

When a hive becomes too crowded, honeybees will perform a process called swarming, where a select group of bees leave with the queen in order to form a new hive. Because the hive's existing queen has left, a new queen must take over for the remaining bees. The swarm cell process is similar to the supersedure process, but when preparing to swarm, bees make a larger quantity of queen cells than they would for supersedure. Swarm cells are located on the bottom of a honeycomb, while supersedure and emergency cells tend to be more centrally located.

Queen bees play a vital role in honeybee colonies, and losing one for too long can mean the end of a hive entirely. Luckily, bees are a well-equipped species that can handle numerous scenarios indicating the end of a queen's reign. If humans can learn anything from honeybees, it's that it pays to bee prepared.

*Bee World* (2010), DOI: 10.1080/0005772X.2010.11417360

# How thermodynamics folds proteins

BY LIAM O'MALLEY, BIOCHEMISTRY, 2023

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

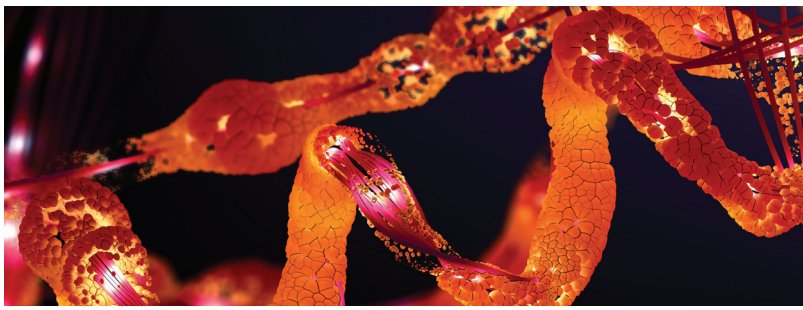
**When you think of a cell,** you might imagine a balloon-like structure with different organelles inside, each performing a specific function. Some might be breaking down molecules and producing energy while others could be storing information. One of the most important jobs in the cell is to produce proteins — in fact, it takes a whole factory's worth of blueprints, assembly, quality control, packaging, and shipping to produce the vast number of proteins that are needed for everyday life.

Like other macromolecules, proteins are constructed from a set of common building blocks called amino acids. Each of the 20 amino acids are small, nearly identical molecules that are made unique by their side chain (also called the R-group). Each side chain lends different chemical properties to the amino acid, changing its role in the overall structure of a protein.

Depending on the sequence of a protein's amino acids and how they're folded together, many different structures can be made. This is vital, as a protein's structure directly begets its function.

Since structure is so important, you might expect there to be robust pathways in place to shape each protein piece by piece so that they are all perfect, with every step of the process being tightly controlled. However, the reality is that proteins are most often assembled by sticking the sequence of amino acids together end to end and then ejecting them into the cytoplasm. Some proteins require further processing, post-translational modification, or export out of the cell. The flexible protein then wriggles and moves about before spontaneously folding itself into the correct shape. Some proteins require a chaperone to help guide them into their final form, but most proteins form through their random movements.

The amazing part is that it isn't entirely the random, chaotic process it seems to be. If a 100-amino-acid protein were to attempt to fold into the correct conformation purely randomly, that is, by moving around until every amino acid is in the exact



spatial arrangement of the final protein, it would take 1.6 x $10^{27}$ *years*. Since smaller proteins can fold within a second, this obviously isn't the whole story.

In the end, the governing forces of protein folding are the laws of thermodynamics. One important equation within chemistry and biochemistry is the Gibbs free energy equation:

$$\Delta G = \Delta H - T\Delta S$$

Where G is Gibbs free energy, H is enthalpy, and T and S are temperature (held constant in the reproduced equation) and entropy, respectively. When a reaction causes the change in Gibbs free energy to be negative (that is, when the system is *producing* energy), it's said to be energetically favorable, and it will occur spontaneously. In other words, the reaction that produces the most energy will occur without any outside forces necessary.

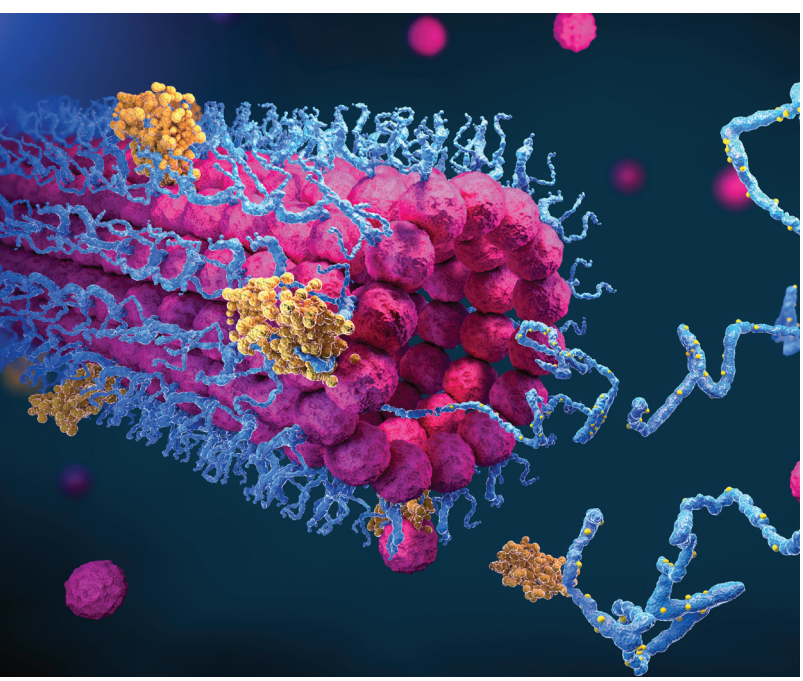
The connection between how these fundamental laws apply to protein folding is illustrated by Richard Dawkins in "The Blind Watchmaker," where he describes how a monkey typing on a keyboard could eventually write a sentence from "Hamlet." It would, of course, take a very long time. However, if the monkey types randomly while you use every correct keystroke, it would only take on the order of approximately 3,000 keystrokes to write a 30-character line.

Within the context of protein folding, biochemists refer to this process as cumulative selection. As a protein flails around with reckless abandon, any amino acids that fall into their most energetically favorable position stay in that position.

Despite the fact that we know how protein folding happens and the basic rules that command the process, we still can't always predict what protein will result from a random sequence of amino acids. This has become one of the most important problems to solve within biochemistry, as it could unlock a whole new genre of protein science.

This mission is at the core of the Critical Assessment of Techniques for Protein Structure Prediction (CASP), a biennial competition in which teams attempt to predict the structure of a protein from just its sequence using artificial intelligence. One competitor, Alpha Fold 2, showed promising results in the 2020 competition (CASP15), being able to predict the correct location (within a certain threshold) of each amino acid with about 90 percent accuracy. While this isn't perfect, this is a huge step forward in the field — who knows how accurate the predictions will be in 2022?

*Nature* (2020). DOI: 10.1038/s41586-019-1923-7



PHOTOS BY SHUTTERSTOCK

# Naked mole rats may help us cure cancer

BY AUDREY GALLIER, COMPUTER SCIENCE, 2023

DESIGN BY KAI GRAVEL-PUCILLO, PSYCHOLOGY, 2022

**Meet the naked mole rat.** It's no typical rodent — it lives underground in Africa, maintains a sophisticated social structure, gets all its food and water from underground tubers, has no fur, and is almost blind. But most impressively, it seems to escape common rules of mortality. Larger animals live longer as a rule, but while the larger rodents rarely live past 10 years, the 5-inch-long naked mole rat can make it up to 30 years old. It shows no normal signs of aging and almost never gets cancer. This makes it a valuable non-traditional model organism in longevity and cancer research.

Non-traditional model organisms are those not commonly used for science, as opposed to the familiar lab rats and mice. They are singled out for their unique biological features. In naked mole rats, researchers study the mechanisms that prevent their cells from deteriorating as this is the cause of both aging and cancer. By studying these animals in captivity, researchers have identified possible protection mechanisms at the genetic, cellular, and protein levels. Most of these mechanisms protect them from cancerous mutations through efficient cellular processes, maintenance, and cleaning.

The naked mole rat genome has been sequenced and compared to those of rats and mice. In these comparative studies, they measured upregulated and downregulated genes and found that DNA repair pathways and cellular protective mechanisms are more active in naked mole rats. More active DNA repair means that cancer-causing mutations are caught and removed sooner. It is not surprising, then, that naked mole rats have a very stable genome. They also have a stable epigenome, which means the chemical markers on DNA are not likely to change.

Telomeres, the DNA structures at the ends of chromosomes, are connected to aging, so researchers are especially interested in how they work in naked mole rats. Telomere replication is a double-edged sword, as it prevents aging but can also introduce mutations. It turns out that naked mole rats replicate their telomeres more often than other mammals. It is likely they are able to do this with minimal damage because of their genome stability and enhanced DNA repair mechanisms.

Another way naked mole rats protect themselves is protein surveillance. If proteins are mutated, denatured, or incorrectly folded, they can cause cancer, and the longer they remain in the cell, the more dangerous they are. Naked mole rat cells identify and destroy damaged proteins faster than other mammals. They also exhibit higher autophagy, or cell self-destruction, rates. This means they have a higher tolerance for oxidative stress, which is thought to have evolved due to their harsh underground habitat that has high levels of carbon dioxide and ammonia. Although they have low antioxidant levels, they are unaffected by oxidation because damaged components are immediately cleaned out.

A final line of defense against cancer lies with cellular mechanisms. In cancer cells, the cell cycle of division and replication is out of control, but naked mole rats are especially good at regulating it through contact regulation, or making sure cells do not become too tightly packed. They also preserve cells' ability to divide as they age. Additionally, these rodents have a low metabolic rate, which minimizes toxic byproducts of metabolism, and a higher tolerance for toxins.

Note that only a few of these findings have been medically confirmed and are rather simply speculations based on measurements. All have been suggested by in vitro studies, and in vivo studies will be needed to get the full picture. Additionally, other animals, such as blind mole rats, elephants, and whales, show similar longevity and resistance to disease, so they also have potential as non-traditional model organisms. Searching for similarities between these animals' adaptations may help researchers zero in on specific protective mechanisms. With more research, our fellow mammals may be able to save human lives.

*Oncogene* (2020). DOI: 10.1038/s41388-020-1355-8

PHOTO BY SHUTTERSTOCK

# The quantum probability of genetic mutations

BY SHREYA NAKHAWA, CELL & MOLECULAR BIOLOGY, 2023

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

**DNA is the genetic information in each of our cells that encodes specific genes and characteristics.** Although this source of genetic information seems like something that should be stable and unchanging, it can be influenced by the randomness of physics phenomena, and these resulting genetic changes can drive evolution. Spontaneous genetic mutations, potentially explained by quantum tunneling, can change the sequence of DNA and greatly impact an organism or even an entire population of organisms.

To better understand the molecule, DNA is made of nitrogenous base pairs that fit together like puzzle pieces to create a double helix structure. If DNA's double helix structure is thought of as a twisted ladder, the paired nitrogenous bases make up the rungs of the ladder, held together with hydrogen bonds. Hydrogen bonding between base pairs provides stability to the DNA molecule while also allowing it to be "unzipped" for replication and translation. These base pairs — adenine, cytosine, thymine, and guanine — only slightly differ from each other, but changes in just one pair can make a huge impact on the gene that it is a part of. DNA is susceptible to these mutations, or changes in its sequence of nitrogenous bases.

Quantum tunneling is a physical phenomenon that can occur anywhere, including inside our bodies on a molecular level. It is characterized by the chance of finding a subatomic particle somewhere it is not supposed to be; though very unlikely, the possibility is never zero. For genetic mutations, hydrogen atom protons can "tunnel" from one side of a barrier — in this case, the hydrogen bonds between base pairs — to the other.

This quantum tunneling may cause spontaneous mutations to arise in our DNA. Normally, adenine (A) pairs with thymine (T), and guanine (G) pairs with cytosine (C). However, when proton tunneling occurs, an A-T base pair might turn into an A-G or C-T base pair because of the displacement of a hydrogen atom, as Slocombe et al. write in their 2021 paper published in *Physical Chemistry Chemical Physics*. This change in base pairs changes the sequence of the DNA, updates the protein that it might encode, and may even result in a different phenotypic trait from what the original gene encoded. Needless to say, just a few mutations can have enormous impacts on the organism inside which they originate.

As an example of quantum tunneling's widespread consequences, mutations are the prime driver of natural selection because mutations in germline cells can be passed onto an organism's offspring. Mutations conferring higher survival rates are selected for within a population over time. Likewise, unfavorable mutations are selected against. Eventually, new, favorable mutations become more common in a population, and unfavorable mutations disappear, leading to a species's evolution. Though mutations originate from a phenomenon that happens at the subatomic level, the result modifies a structure so essential to our biology that it can shape the future of a species.

*Physical Chemistry Chemical Physics* (2021).
DOI: 10.1039/D0CP05781A

PHOTO BY SHUTTERSTOCK


# A waking nightmare

## Sleep deprivation and circadian rhythms in the midst of addiction

BY ANNABELLE MATHERS, CIVIL ENGINEERING, 2022

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

**It is commonly said that a sleep-deprived person has the mental performance of a person impaired by alcohol.** However, the relationship between sleep and substances, such as drugs and alcohol, may be deeper than a simple comparison. Sleep itself is a significant factor in physical health and mental performance, yet many aspects of sleep remain elusive to researchers. Circadian rhythms essentially control many of the patterns of sleep, but their exact dynamics and tendencies are not entirely clear. The consumption of psychoactive substances, another confounding factor that influences the brain, is known to alter circadian rhythms, and researchers have begun studying the interactions of those substances and circadian rhythms to obtain a greater understanding of both. More specifically, experts have been evaluating sleep patterns during addiction, and how disrupted sleep and substance use disorders (SUD) may cyclically encourage one another.

Circadian rhythms, although often associated with sleep, are not solely mechanisms of sleep nor wake rhythms. Instead, they refer to any diurnal (24-hour) pattern of biological behavior, particularly on a cellular level, that occurs in response to external stimuli (zeitgebers) that train the rhythm to continue in the absence of any stimuli. For example, visible light is a zeitgeber that affects circadian rhythms, but those rhythms continue even when a particular light/dark pattern is not present. Research now suggests that psychoactive substances might be zeitgebers, as they have observed that the biological effects of drugs and alcohol persist during sober withdrawal.

The definition of the internal circadian clock also continues to change, heavily affecting how experts view sleep and SUD. The suprachiasmatic nucleus (SCN) in the hypothalamus was once thought to be the sole rhythmic clock in the body, but it is just the central coordination component of a system of peripheral clocks within different organs, tissues, and cells. The rhythmic responsibility in the body is dispersed, which may increase the ability of substances to alter the SCN to indirectly affect integral circadian rhythms by desynchronizing peripheral clocks that are under the SCN's control. As a result, previously unaffected biological rhythms are secondarily desynchronized.

Given the multiplicity of biological rhythms, experts classify sleep as an effect of both the light/dark cycle and the homeostatic tendency toward sleepiness as one's waking hours increase. These cycles are interrupted and repatternized when a person routinely uses psychoactive substances, potentially disrupting the centralized synchronicity of SCN rhythms and associated cycles of mood and cognition. Psychological condition is a factor in relapse and addiction. Thus experts propose the idea that SUD and circadian disruption are cyclically related (bidirectional); the effects of addiction encourage rhythmic incompatibility that results in physiological and psychological effects that make someone more likely to relapse. However, experts continue to debate whether sleep deprivation from irregular sleep patterns truly results from physiological and chemical effects of SUD or if the unpredictable nighttime life often associated with addiction is the culprit. Furthermore, it is rather unknown to what extent the substance-induced disruption of rhythms, when combined with irregular eating and physical activity, may affect sleep patterns. This conflict brings into question whether drugs and alcohol themselves are the true zeitgebers that train these bodily patterns.

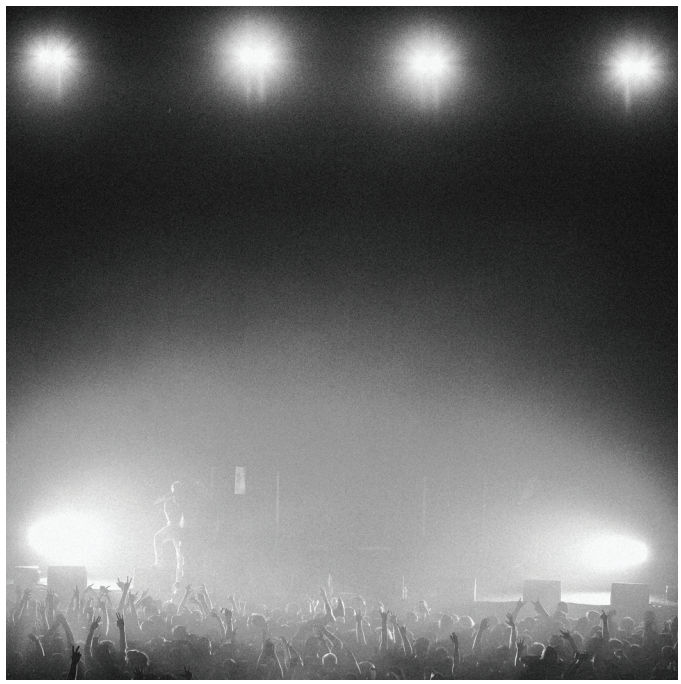
Some of the most common experimental observations note that chronic overconsumption of alcohol correlates with insomnia and irregular secretion of melatonin. Insomnia and generally disrupted sleep typically continue during recovery from depressants like alcohol and are often related to depression and health issues that may encourage relapse. Turbulent sleep is also an effect of stimulants like amphetamine and cocaine. Many studies are conducted through conventional experimentation, but other studies require subjects to personally report and describe their experiences in a less-controlled environment. Experts struggle to reconcile the subjectivity of these reports. In general, studies come to largely different conclusions, oftentimes arguing directly against the results of another. For example, some researchers argue that sleep patterns of alcoholics are more related to age at initial consumption than quantity of consumption.

Ultimately, do all of these sleep disruptions actually disrupt the circadian control held by the SCN? Experts remain unsure if the effects of substance-induced sleep deprivation are superficial or a result of sustained changes in deeper biological rhythms. Regardless, there is enough compelling evidence of a relationship between sleep and SUD to motivate continued studies on the dynamics of circadian rhythms associated with sleep and, by extension, substances. As insight into circadian rhythms deepens, the hope remains that a greater understanding of the body's interdependent rhythms can help address the complications of chronic sleep deprivation and addiction.

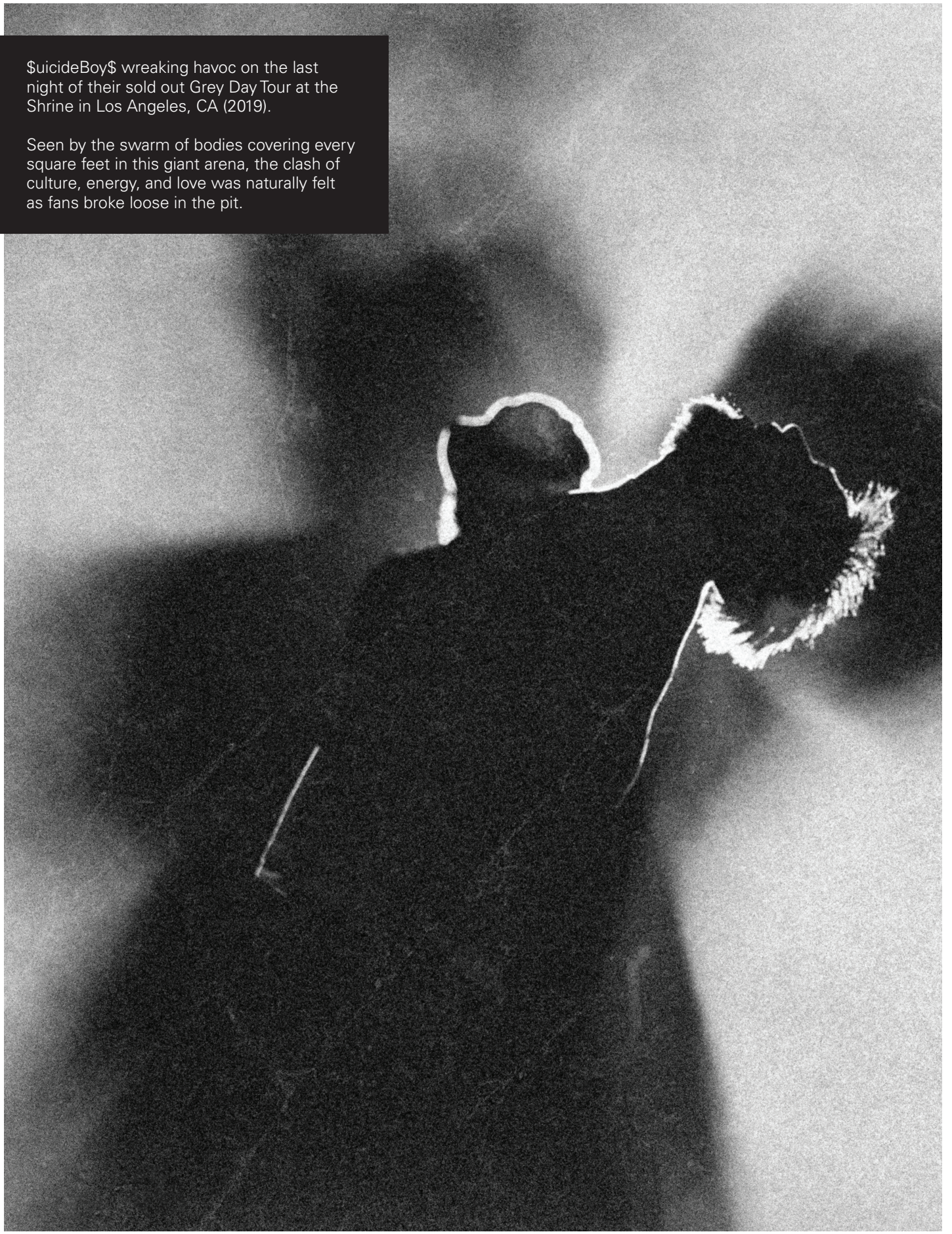
PHOTO BY SHUTTERSTOCK

*Behavioral Neuroscience* (2014). DOI: 10.1037/a0036268
*Sleep Medicine Reviews* (2012). DOI: 10.1016/j.smrv.2011.03.004

# CHAOS IN CONCERT



PHOTOS BY
MUHAMMAD ELARBI



$uicideBoy$ wreaking havoc on the last night of their sold out Grey Day Tour at the Shrine in Los Angeles, CA (2019).

Seen by the swarm of bodies covering every square feet in this giant arena, the clash of culture, energy, and love was naturally felt as fans broke loose in the pit.

# THE LITERAL BUTTERFLY EFFECT

BY KAELEN ENCARNACION, BIOLOGY & ENGLISH, 2021

DESIGN BY ETHAN WAPLE, CELL & MOLECULAR BIOLOGY, 2023

**In 1952,** famous science fiction writer Ray Bradbury published a short story titled, "A Sound of Thunder." Set in the year 2055, time travel has become a real (and profitable) technology, and a group of affluent hunters goes back in time on a guided safari to kill a *Tyrannosaurus rex*. Although the safari company has strict procedures to minimize any changes that could occur in the future because of their actions — staying on the levitating path, only killing "tagged" species that were supposed to die within a few minutes anyway, not leaving any artifacts in the past like bullets — one hunter loses his nerve and steps off the path. Upon returning to the present, they find reality irrevocably changed: The English language has been altered, and the fascist candidate who originally lost has now won the presidential election. Looking at the mud caked under his boots, the hunter finds a single crushed butterfly.

It wasn't until 20 years after the story was published that the term "butterfly effect" was officially coined by meteorologist Edward Lorenz who discovered that tiny, "butterfly-sized" changes made at the start of his computer weather models led to dramatically different and unpredictable results, from clear skies to devastating storms. Nevertheless, Bradbury's story is one of the most well-known examples of this amplifying tenet of chaos theory, and while time travel and hunting dinosaurs are still only works of science fiction, the idea that something as small as a butterfly can have a massive large-scale effect in the future is very much true for ecology and climate change.

Conservation efforts and climate change have been major points of contention in political and international spheres, especially in recent years. Since 1970, global carbon emissions have increased by over 90 percent, primarily because of fossil fuels and human activities that drive habitat loss and deforestation. About one-third of the world's species are projected to go extinct in 50 years. In 2018, headlines broke out in a panic when the United Nations Intergovernmental Panel on Climate Change (IPCC), a body composed of climate researchers from over 40 countries, released their special report on the current climate situation. In this report, they analyzed over 30,000 scientific papers and presented options for policymakers to implement systemic changes to combat the Earth's increasing temperatures. According to the IPCC, we had a little over a decade to mitigate climate change before we faced catastrophic and irreversible consequences. That was three years ago.

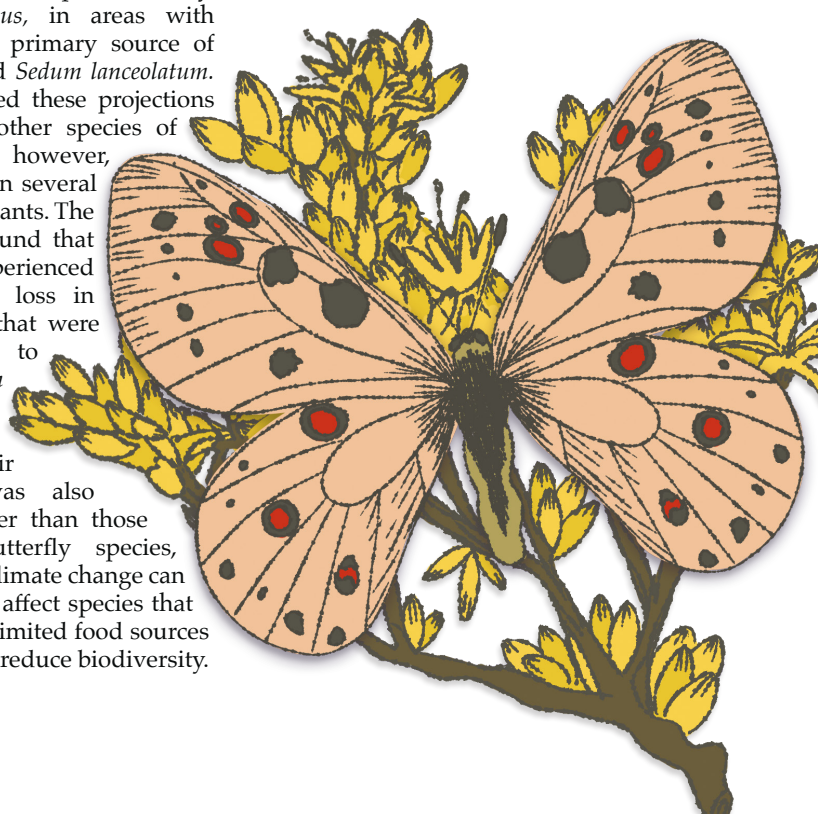
The causes of climate change and species endangerment are clear. But while the future is projected to be bleak, the true extent of their effects can be extremely difficult to predict like "A Sound of Thunder" illustrates. However, researchers from the University of Alberta have found an interesting way to better quantify the complex impact climate change has on ecosystems.

By using climate models that simulate the migration patterns of specific butterfly species in North America, the researchers were able to analyze the distribution of an alpine butterfly, *Parnassius smintheus*, in areas with and without their primary source of food, a plant called *Sedum lanceolatum*. They also compared these projections to those of four other species of alpine butterflies; however, these species fed on several different types of plants. The researchers had found that *P. smintheus* experienced significant habitat loss in dry-climate areas that were no longer able to grow *S. lanceolatum* compared to areas of normal climate. Their habitat range was also significantly smaller than those of the other butterfly species, highlighting how climate change can disproportionately affect species that rely on specific or limited food sources and can ultimately reduce biodiversity.

These findings have huge implications in modeling species distribution in response to climate change. They show the importance of tracking not only the direct effects, such as migration patterns and population numbers, but also the indirect effects, such as temperature and local food availability. This focus on trophic, or food-related, structure could be applied towards modeling ecosystems that are much larger and more complicated than just butterflies and plants, especially since the effects of climate change will likely spread to multiple species in a food web.

Based on the rate that human-driven climate change is severely influencing factors like the environment, weather, and biodiversity, Earth has a countdown timer. Until the world's governments significantly crack down on carbon emissions and implement meaningful change in the ways we interact with ecosystems, manage waste, and generate energy, hopefully we can avoid stepping on any butterflies in the meantime.

*Global Change Biology* (2020). DOI: 10.1111/gcb.15068



# Studying the climate is chaotic.
## Could physics help?

BY MAYA KRAUSE, ENVIRONMENTAL SCIENCE, 2022

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

**The chaos of Earth's climate has led some to doubt the validity of anthropogenic (human-caused) climate change currently affecting the planet.** Climate deniers commonly respond to scientific evidence of global warming with statements along the lines of "hasn't the climate always been changing?" While it is true that Earth's climate has often fluctuated throughout planetary history, Stephanie Herring, a climate scientist for the National Oceanic and Atmospheric Administration (NOAA), states that scientists are primarily concerned that changes associated with the recent warming trend are occurring faster than at any other time in the history of human civilization. However, because of the unpredictability of Earth's conditions, climate scientists struggle to assess the full impact of climate change. How can scientists predict the causes and effects of modern climate change when the climate itself is so chaotic?

One possible route of study is through physics. A study in *Reviews of Modern Physics*, led by Valerio Lucarini and Michael Ghil, proposes to address the gap in current climate predictions by using physics-based models to mathematically evaluate the interplay between normal climate variation, human effects, and natural influences. According to the authors, current climate change models face two main flaws. The first flaw is that models have limited specificity regarding the mean global temperature after the concentration of carbon dioxide in the atmosphere doubles. Current predictions compute an increase between 1.5 and 6 degrees Celsius despite more than 40 years of modelling. Secondly, models typically struggle to predict the point at which a system is irreversibly changed, also known as a tipping point. These areas are key factors in evaluating the impact of anthropogenic climate change, thus finding the source of these flaws is critical.

Experts believe that the flaws present in current climate models stem from the failure of mathematical models to reproduce the elements of chaos theory that are present in climate systems. Chaos theory is a well-studied mathematical concept which describes the large impact of one relatively small action on the outcome of a system. The basis for the theory was formed in 1961 by a meteorologist named Edward Lorenz, who used early computers to attempt to predict the weather. He found that if he ran the weather model using a value containing three decimal places, such as 0.506, he produced a wildly different prediction than if he ran the model using a value containing six decimal places, such as 0.506127. This led to the discovery that tiny measurement errors grew to the extent that they impacted the eventual prediction significantly. However, the differences between models due to the erroneous measurement is deterministic,

> "How can scientists predict the causes and effects of modern climate change when the climate itself is so chaotic?"

meaning the chaos can be predicted, which allows scientists to incorporate the "randomness" into their models. The combination of natural elements such as cloud formations, ocean currents, wind patterns, and solar radiation creates a complex and chaotic climate system on Earth. Lucarini and Ghil posit that scientists' ability to predict the deterministic elements of this system plays a critical role in developing accurate climate change models.

Subsequently, Lucarini and Ghil developed a model that provides the tools to more easily incorporate the principles of chaos theory into climate change predictions. The framework may help climate scientists increase the accuracy of models by improving the evaluations of how human emissions of carbon dioxide disrupt the natural variability of the climate. Lucarini and Ghil's model also helps scientists determine the amount of detail necessary to produce accurate models. Ideally, this framework can help advance an interdisciplinary approach to evaluating the impacts of climate change and encourage climate scientists to incorporate mathematical principles into their models to improve their predictions.

While climate deniers may try to argue otherwise, human activities are causing increased global temperatures compared to natural fluctuations in climate. Scientists are constantly working to optimize models that predict the impact of global warming. As the world becomes increasingly affected by climate change, physics may be the answer to accurately evaluating what chaotic future lies ahead.

*Reviews of Modern Physics* (2020). DOI: 10.1103/RevModPhys.92.035002

PHOTO BY SHUTTERSTOCK

# MASTERS OF SURVIVAL:
## IS THE DESERT TRULY DESERTED?

BY YAEL LISSACK, BIOENGINEERING, 2021
DESIGN BY IAN PROULX, BIOENGINEERING, 2022

**The first time I fell in love was in the Sonoran Desert.** I had just pulled over to the side of the road and there it was. An Ocotillo, in all its glory, stood proudly before the rugged landscape. Its fluid tentacle-like stems pointed towards the sky, like a sea anemone frozen in turbulent water. As I got closer, I could see the branches were comprised of hundreds of small disks, each attached by their narrow edges to an undulating green stem. Displays of otherworldly features like these are the key to understanding how plants survive in unforgiving climates.

Deserts receive an average of 10 inches of rain per year, making them some of the harshest biomes on earth. Subsisting on minimal water and extreme temperatures is no easy task. One may think that extreme drought would leave these places devoid of life; however, the desert is far from deserted.

> "Desert plants have evolved not only to survive, but to enrich the land around them."

2,500 species of cacti fall within the Cactaceae family. Of these numerous species, all but the *Rhipsaslis Baccifera*, or "Mistletoe Cactus," are native to the Americas. What allows species of cacti to thrive in arid climates is precisely what separates them from all other plants: their leaves, or lack thereof. Most green plants convert sunlight into energy via 3-carbon (C3) photosynthesis and generate carbon dioxide ($CO_2$) as a byproduct. Stomata, or pores on the surface of leaves, open to allow the exchange of atmospheric oxygen and $CO_2$. This process occurs during the day throughout the surface of the leaf and is the most efficient type of photosynthesis under normal light and moisture conditions. In excessive heat and drought, however, keeping stomata open under the potent rays of the sun means that water stored within the plant has a clear path to evaporate or transpire. Water is the most precious resource in the desert, and any loss of it should be avoided. To overcome this obstacle, cacti have developed unique drought-resistant adaptations in the way they photosynthesize and store water.

Through a process known as crassulacean acid metabolism (CAM) photosynthesis, cacti have evolved to open their stomata only at night when temperatures are low in order to reduce transpiration of water. Instead of leaves, CAM plants often have thick, waxy stems, which perform the essential work of photosynthesis. Having tough, hydrophobic stems instead of thin leaves allows cacti to stockpile $CO_2$ at night without risking too much water loss from the heat of day. This is the cacti's method of drought insurance.

Though cacti are the quintessential desert plant, they are not the only ones to have adjusted to life in arid landscapes. A member of the legume family, the Mesquite tree is one of the most well-suited and beneficial plants in the Sonoran Desert of Mexico and the Southwestern US. This tree can grow up to 20 feet high and flaunts narrow leaves interspersed with long bean pods that are velvety to the touch. Mesquite's small leaves reduce the surface area of water evaporation, while its root system is the most extensive of its kind. Not only do its roots grow laterally outwards to trap rainwater, but its tap root can grow up to 190 feet deep, allowing it to draw moisture directly from the water table in dire periods of water scarcity.

The mesquite tree is a master drought survivalist that also serves as an indispensable member of its ecosystem. It provides food and shade to desert animals, and its roots fixate nitrogen from the air and transform it into a usable nutrient source for other nearby plants. According to the Michigan Native American Ethnobotany Database, the leaves, roots, and bean pods of Mesquite are used as food and medicine by the Apache, Comanche, Havasupai, and Isleta tribes among others. Desert plants have evolved not only to survive, but to enrich the land around them.

Thousands of species have evolved to resist drought conditions of the world's most severe deserts. As climate change accelerates desertification and drought, these specialized organisms will be put to the test for survival. Preserving the biodiversity of desert species is a testament to the vigor of humans, plants, and animals alike.

PHOTOS BY SHUTTTERSTOCK AND PIXABAY

# DANGEROUSLY UBIQUITOUS

## The negative effect of nanoplastics on human health

BY MARIA HARSVIK, BEHAVIORAL NEUROSCIENCE, 2023

**From the deepest ocean trenches to the tap water in our kitchen,** nanoplastics have pervaded virtually every last crevice of Earth. The miniscule particles, resulting from the degradation of plastic objects, are less than 100 nanometers (nm) and can be ingested, inhaled, or incorporated by dermal contact. It is estimated that just by eating, drinking, and breathing alone, Americans ingest at least 74,000 microplastic particles each year. Breaking that down, that means Americans ingest five grams of plastic a week. During the process of plastic manufacturing, chemicals including plasticizers, pigments, and stabilizers are added. It is the leaching of these chemical additives that pose adverse effects to humans as the nanoplastics seep into the body and reach one's cells.

Due to their size, nanoplastics have the ability to cross endothelial barriers, translocating into red blood cells and travelling along intracellular spaces. Eventually, through transport by microfold cells, nanoplastics may even reach lymphoid tissues and blood vessels. Access to the bloodstream means an entrance point to metabolic and endocrine organs, specifically the liver and kidney. Alternatively, nanoplastics can attach to the lining of the gut; this is believed to damage one's health by directly affecting the composition and diversity of the intestinal microbiome. Cell culture studies using intestinal cells conducted at the University of Fribourg in Switzerland demonstrated that polystyrene nanoparticles were able to overcome the gastrointestinal barrier and translocate into the tissue underneath. When in the gut, nanoplastics can damage cells and activate immune cells' inflammatory reactions. Furthermore, inflammation from nanoplastics disturbs the gastrointestinal processes by creating an imbalance in gut bacteria known as dysbiosis which has occurred in mice models. Although nanoplastics are hypothesized to contribute to these microbiotic changes, more research needs to be done to paint a full picture of the long-term impact on the gastrointestinal system. In vitro approaches and animal models give us insight into the effects of nanoparticles, but the extent of their application to humans remains unclear.

The pervasiveness of nanoplastics assures that they will continue to pollute the environment and make their way into our bodies. The best way to reduce one's exposure to them is to help in cleanup efforts to remove plastics from the environment and change our daily routines. Something as simple as individually making the decision to use more environmentally-friendly products and reduce plastic intake has an important impact.

*Science Bulletin* (2020). DOI: 10.1016/j.scib.2020.08.003

DESIGN BY PARKER HITT, BIOLOGY, 2024

PHOTO BY CHESAPEAKE BAY PROGRAM

# STICKING TOGETHER FOR LIFE (QUITE LITERALLY)!

BY SOUMILI DEY, CELL & MOLECULAR BIOLOGY, 2024

**Outer space is notorious for its inability to support living organisms.** Extreme temperatures and low pressures prevent organisms from surviving. Additionally, ultraviolet (UV) radiation from the sun has the potential to dissolve cell membranes and the DNA encapsulated within them. As the search for living entities in outer space continues, a team of researchers found that some bacteria may have the ability to survive amidst this harsh environment. The hypothesis is called "panspermia," and it claims that bacteria can survive in space and migrate between planets. To test this hypothesis, astrobiologist Dr. Akihiko Yamagishi and his team used a robust bacterium called *Deinococcus*, which can survive in extreme conditions such as the cold, strong acidity, and high radiation. This makes it an ideal candidate to test the ability of bacteria to survive in space.

Three samples of *Deinococcus* of different thicknesses were placed in small wells in metal plates. These include three cell pellet thicknesses: 100 micrometers, 500– 1,000 micrometers, and 1,000 micrometers. Additionally, three treatment conditions for the bacteria were prepared: a control kept on Earth, a sample inside the International Space Station (ISS), and one outside the ISS. The bacteria were monitored for three years, and were brought to Earth every year for analysis. The results demonstrated that all the samples with pellets of 100 micrometer thickness were burned due to high exposure to UV radiation. In both the control and the samples outside the ISS with cell pellets of 500-1,000 micrometer thickness, bacteria on the surface of the aggregate died. However, these dead bacteria created a layer of protection that allowed bacteria inside the aggregate to stay alive. The bacteria with the 1,000 micrometer thickness had the highest survival rate. Based on the survival data in the sample with the 1,000 micrometer thickness, scientists predicted that cell pellets with this thickness could survive up to eight years in outer space. Yamagashi believes that *Deinococcus* could survive travel on the shortest orbit from Earth to Mars. This study presents a breakthrough in the field, and with these recent findings, a new term has been coined called "massapanspermia," or the phenomenon that bacterial colonies can survive in aggregates in space. This brings scientists one step closer to the possibility of interplanetary forms of life, but more studies are required to help answer the many questions that still remain.

*Frontiers in Microbiology* (2020). DOI: 10.3389/fmicb.2020.02050

PHOTO BY NIH IMAGE GALERY

# FROM A SUPERNOVA COMES A SPIDER

BY ABIGAIL POTTER, PHYSICS & PHILOSOPHY, 2023

DESIGN BY SOPHIE PATE, ARCHITECTURE & DESIGN, 2024

**The night sky is breathtakingly captivating.** It entrances viewers with twinkling lights that allow for navigation, make shapes, and tell stories. As technology advances, people are even able to put manmade lights into the sky in the forms of planes or satellites. Often those observing the sky try to tell the two apart, which is possible by detecting movement or flashes of light. However, sometimes these flashes of light are indicators of a star long forgotten whose remains spin so fast that they appear on Earth as a light turning on and off.

These flashes of light are known as pulsars, named for how they appear to pulse in the night sky. Pulsars are not actually stars, rather they are the remains of one. When a massive supergiant star collapses, the stellar death creates an explosion known as a supernova, and the dense amount of material collected at the center can form a neutron star. Should the material be highly magnetic, there is a chance that the neutron star begins to rotate, creating a pulsar.

It is suspected that pulsars siphon matter and momentum from a nearby companion star, increasing its spin rate; this would explain why pulsars have different speeds. The slowest pulsars ever detected spin once per second and are aptly named slow pulsars. Fast pulsars on the other hand can spin hundreds of times a second. Millisecond pulsars are the fastest, spinning with millisecond rotation periods. While a millisecond pulsar devours its companion star, the binary system is referred to as a spider system. Depending on the size of the companion star, the system is either named a black widow or a redback. This is derived from the two species of spiders whose females are observed to consume smaller males after mating, similar to how the pulsar "consumes" the lighter companion star.

While fascinating, few of these spider systems have been found because plasma from the companion star can hide pulsations of the pulsar, disguising them in radio pulsar surveys. However, that never stopped astronomers from speculating some celestial objects to be spider systems.

One such example is the source now known as PSR J2039-5617 whose existence has been known since June of 2014. Originally observed as a source of gamma rays, astronomers quickly analyzed its X-ray emissions and predicted it to be a redback. However, with the companion star's plasma blocking the millisecond pulsar's radio pulsations, it was impossible for astronomers to reclassify the object.

Millisecond pulsars emit more than just radio pulsations– they also emit gamma-ray pulsations. Gamma-ray emissions are unique in the sense that they do not experience the same distortion and are easily detected by the Fermi Gamma-ray Space Telescope's on-board Large Area Telescope (LAT). As such, searches for isolated millisecond pulsars are now streamlined. Binary spider systems, on the other hand, require some additional orbital parameters to be set. These parameters are necessary as they account for the Doppler shift, which would cause the pulsations to appear smeared out on readings if not accounted for.

The scientist team at the Albert Einstein Institute compared periodic X-rays and intensity of light measured to determine the necessary parameters including orbital period and spin frequency. The sky positions scanned were determined by precise Gaia data.

Using these constraints, the scientists used the distributed volunteer computing system Einstein@Home to comb through data gathered by Fermi since its launch in 2008. The website splits data into millions of smaller chunks that are able to be processed on an average computer within a few hours, computing data while volunteer's computers are idle.

The search revealed a signal with a spin frequency of 377 hertz, which was used along with the companion star's radial velocity measurements to calculate the mass ratio of the companion star to the pulsar. With the mass ratio stating that the companion star is both larger and of higher mass than those in black widow systems, the redback status of the system was confirmed, officially naming the source PSR J2039-5617.

This redback identification is the first to be completed through gamma-ray pulsations, leading to what is hopefully a new way to properly classify pulsars. With more pulsars to study comes many new insights. For example, pulsars can be used as clocks, tell us about gravitational waves, and may lead to the discovery of alien planets. While often overlooked as artificial, these flashes of light can uncover mysteries about the universe.

*Monthly Notices of the Royal Astronomical Society* (2020). DOI: 10.1093/mnras/staa3484

PHOTOS BY UNSPLASH & SHUTTERSTOCK

# ONE DATA POINT:
## BAYESIAN INFERENCE AND THE LIKELIHOOD OF LIFE

BY CARA PESCIOTTA, PHYSICS, 2022

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

**Suppose Earth's clock is reset to its very beginning.** This would take us back over 4.5 billion years, passing the first human around 7 million years ago and the first microscopic organism 3.5 billion years ago. Then, we let the clock rerun. Would life evolve as it did for humanity, or is our existence a statistical anomaly?

To properly discuss this question, we must first consider the likelihood of abiogenesis, or the development of life from inanimate materials. One could imagine that if conditions on Earth were by chance exactly as needed for abiogenesis, life's onset may not be all that common and a reset Earth would likely remain lifeless. On the other hand, abiogenesis could be almost inevitable given Earth's properties. One condition to contemplate is whether organic material emerged from Earth's formation or a rain of asteroids, as this implies either an inevitable path to life or a random occurrence.

Assuming life does form, Earth's real time scale demonstrated a long period of evolution until humans and other intelligent life surfaced, stirring questions of how likely intelligent life is to form given how long it took Earth. This produces four potential options compounding the likelihood for abiogenesis with intelligence: rare life and rare intelligence, rare life and common intelligence, common life and rare intelligence, and common life and common intelligence.

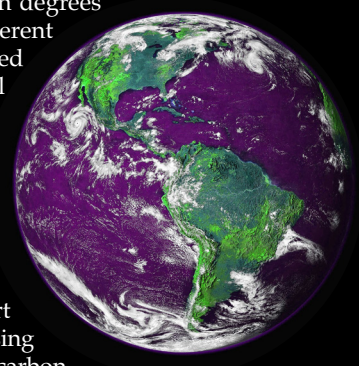
Scientists, of course, cannot turn back Earth's clock but are instead interested in these thought experiments to demonstrate the chances of success for life on other planets. Earth's narrative cannot tell the whole story, as most exoplanets do not possess characteristics resembling Earth's, but it's a good place to start.

David Kipping, an assistant professor at Columbia University, used this Earth clock scenario to ask what Earth implies about other planets. Kipping's article, "An objective Bayesian analysis of life's early start and our late arrival," forgoes the conventional assumption that some aspect of Earth's timescale, like abiogenesis, is an axiom of planetary evolution. The paper instead considers Earth the only known data point in a large, but undiscovered, data set. This new assumption allows for more outcomes to be factored into the equation at one time, studying both abiogenesis and intelligent life formation in concordance with each other.

Kipping accomplishes this using a statistical tool called Bayesian inference, which allows a hypothesis to be updated as more information becomes available. Bayesian inference is based on Bayes' theorem, a relatively simple equation taught in most introductory statistics courses, and real-world applications of the equation can actually be quite interesting.

The equation uses known probabilities of two events to determine the probability of one of the events occurring given that the other already has. For example, one could determine the probability that a 7 is chosen from a deck of cards given that the card is red, or one could determine the probability that someone actually has a disease given that they test positive for it. It is a popular technique used in medicine, environmental science, finance, and even film.

Bayesian inference is simply Bayes' theorem with probability distributions instead of precise probabilities. This allows Kipping to use properties from his one data point, Earth, with high degrees of uncertainty, testing a number of different early-life theories that are heavily contested by scientists around the world. Careful analysis led to Kipping's conservative conclusions agreeing with many early-life assumptions.



Kipping's analysis showed that abiogenesis is 2.8 times more likely to be a fast process than a slow one when using the earliest microfossil evidence as the start of life. This number jumps to 8.7 when using the earlier, more disputed evidence of carbon depletions in zircon deposits that may have been caused by carbon uptake from early organisms. Analysis also showed that the probability of intelligence is less sure, with a rare-intelligence scenario being slightly favored at 3-2 odds against a common-intelligence one.

Kipping is careful to emphasize that the data set only includes Earth in its Bayesian inference, and the conclusions should be interpreted as such, though these findings are still encouraging for scientists exploring life on other planets. A high likelihood of abiogenesis indicates that looking for biosignatures is a useful approach to finding life, and the close call on intelligence means technosignatures should not be ruled out either.

So, are scientists' efforts in the search for extraterrestrial life futile? We may not know for sure, but Kipping's findings are promising, and with any luck, we will soon acquire a second data point.

*PNAS* (2020). DOI: 10.1073/pnas.1921655117

PHOTOS BY PIXABAY

# WHAT IS ENTROPY?

BY DATTU KALLURI, BIOCHEMISTRY, 2022

**One of the most fundamental laws of thermodynamics states that entropy is always increasing.** But what exactly is entropy? Simply put, entropy is a measure of randomness or loss of energy available to do work.

One of the first mathematical formulations of entropy was published in the 19th century by Sadi Carnot in his book titled "Fundamental Principles of Equilibrium and Movement." In his book, Carnot states that any moving engine loses "moment of activity" — or energy able to do useful work. Entropy can be decreased locally, meaning that, if some force or "agent" acts upon an open system, it can decrease the entropy of that system at the cost of increasing the energy of the system overall.

In the late 1860s, scientists began to utilize probability to explain the fundamental principles of entropy. Entropy was characterized as the distribution of microstates within a system. Because of the probabilistic nature of this definition, it leads to some puzzling questions. If entropy increases over time but is also a probability, who is to say what that length of time is? For example, by sheer chance the entropy of a system could decrease, but we know that in the long term it will increase. Can we arbitrarily define a period of time or say that the laws governing entropy have been violated in this length of time?

Even more complications in the theory of entropy arose when James Clerk Maxwell proposed his now infamous thought experiment: Maxwell's Demon. In this theoretical experiment, a gas is enclosed by a box with a partition that can open and closed at will by a "demon." The omniscient "demon" is able to open the partition at just the right times to allow only the fast particles into one side and the "slow" particles into the other side. Because temperature is directly related to the speed of particles, this means that the hot side of the box gets hotter while the cold side gets colder. Theoretically, this would violate the second law of thermodynamics by decreasing the entropy of the system.

In 1929, Leo Szilard, a Hungarian physicist who worked on the Manhattan Project, published a now famous response to Maxwell's Demon. In any conceivable real-world system, the demon would need to be able to measure the speed and direction of the particles to know when to open the partition. The amount of energy the demon would expend by taking this measurement would mean the demon increases entropy overall, even if the entropy of the box itself decreases. It raised a point that is now fundamental in thermodynamics and information theory: The acquisition of information itself is work and expends energy.

Entropy is applicable to virtually everything we experience in our daily lives — boiling water, pistons in an engine, and heat from the sun. It determines the thermodynamic properties of all the molecules we interact with. For example, when salt is added to water, the water boils at a higher temperature. This is because the entropy of the water has increased after being mixed with another molecule, and entropy difference between liquid water and vaporized water has decreased. This means that there is less "incentive" for water to vaporize.

But entropy is far more profound than just heating or cooling. In its purest sense, entropy simply means there is an inherent decay to the universe. The universe initially started off with "information" that can never be regained and will eventually degenerate into nothingness. In fact, entropy itself is the arrow of time — differentiating the past from the future.

The concept of entropy is still an area of intense research, and physicists continuously try to find exceptions. And learning more about entropy itself has far reaching implications from the behavior of condensed matter to quantum computing.

DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

# Microfluidic mixing

## Stirring the tiny drink

BY RYAN BRADY, CHEMICAL ENGINEERING & BIOCHEMISTRY, 2022

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

**From the air you breathe to the water you drink,** almost all substances in the natural world are mixtures of numerous components. Air is 78 percent nitrogen, 21 percent oxygen, and the remaining 1 percent is a variety of other substances, including argon and carbon dioxide. Intermolecular interactions determine the formation of mixtures in the natural environment, but humans have been creating their own mixtures since prehistoric times. Mixing is used in everything from construction to food preparation, and most chemical processes require precise mixing to ensure mixture uniformity. Generally, this is done in very large mixers; however, recent advances have allowed mixing to be conducted at a much smaller scale of microliters instead of thousands of liters.

> "Mixing is used in everything from construction to food preparation ... recent advances have allowed mixing to be conducted at a much smaller scale of microliters instead of thousands of liters."

Microfluidic mixing is an up-and-coming technology which utilizes either active or passive mixing on a small scale to uniformly mix small volumes of fluids. This can be useful specifically for biological mixtures where reagents can cost thousands of dollars per milliliter. By miniaturizing mixing, complex biological analysis can be conducted on smaller scales, allowing for single-cell analysis. Quantitative polymerase chain reaction utilizes these microfluidic mixing technologies in order to analyze the protein production on a cellular level. For example, cells can be separated prior to DNA measurement, allowing the protein production of each individual cell to be determined. Additionally, enzymes which normally are used to detect specific proteins could be done in flow settings, allowing for the collection of real-time data. Outside of biochemistry, similar technologies could be used to control reactions which produce large amounts of heat. Finally, this method could be used in environmental testing to bring assays from the lab bench to the field. Technologies like these allow much more precise data to be collected, but require highly precise mixing of reagents.

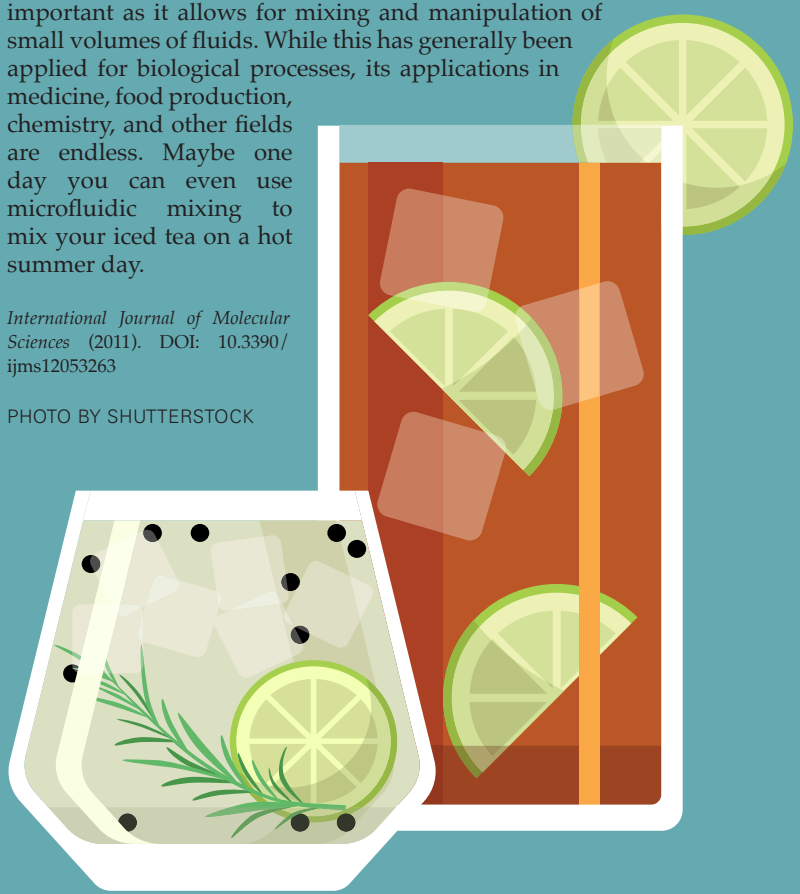
There are two main types of microfluidic mixing. The first is active mixing, which uses motion or electricity in order to mix substances. When working with small volumes of fluid, significant forces can be generated via induced dipole activity from an electric field. By pulsing the electric field, the force direction can be quickly changed, inducing mixing within the fluid. This technology was demonstrated on a device which was only five millimeters long with a width of less than one millimeter. Further, temperature gradients can be applied in the same way to induce convection currents within the fluids. The final type of force that can be applied in this manner would be an electromagnetic force. By rapidly changing the electromagnetic field, fluids containing charged ions will be exposed to changing forces and will be rapidly intermixed.

The other type of microfluidic mixing is passive mixing. Passive mixing utilizes geometry in order to mix fluids. Any flowing fluid will be subjected to friction from its contact with the walls of the pipes or tubing it is flowing through. This frictional force can be used to manipulate the flow direction to promote intermixing between fluids. The simplest form of this mixing is lamination. Lamination brings the fluids together through contact and interactions with the walls, driving the mixing to completion. Because of the small scale, this can be especially effective when low volumes are being mixed. Another type of passive mixing utilizes multiple flow channels to promote mixing. The fluid is split into multiple channels and the intersections between these channels become mixing regions where the different fluids can interact. This similar mixing architecture can be introduced in three dimensions to further improve mixing. Common structures include a serpentine pattern which alternates 90 degree turns in the vertical and horizontal directions. These changes in how fluid contacts the surface impacts the mixing, as surface contact increases frictional forces, slowing down fluid motion and allowing intermixing.

Overall, both active and passive mixing allow for effective mixing of small volumes of fluids. This is important as it allows for mixing and manipulation of small volumes of fluids. While this has generally been applied for biological processes, its applications in medicine, food production, chemistry, and other fields are endless. Maybe one day you can even use microfluidic mixing to mix your iced tea on a hot summer day.

*International Journal of Molecular Sciences* (2011). DOI: 10.3390/ijms12053263

PHOTO BY SHUTTERSTOCK



# How precisely can we keep time?

## Physicists near the universe's fundamental limit

BY NOAH HAGGERTY, APPLIED PHYSICS, 2024

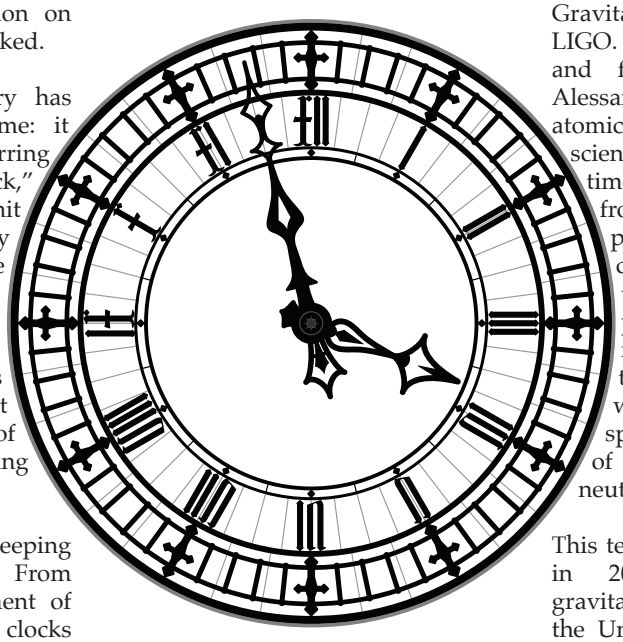
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

**By the mid-twentieth century,** quantum mechanics was the most contentious debate in physics, with its revolutionary descriptions of the interaction of particles in terms of probability, uncertainty, and discrete values. Albert Einstein infamously disagreed with one of its defining principles that reasoned the shorter the duration of a measurement on a particle, the less precisely the particle's frequency can be known. This tradeoff, known as the Heisenberg uncertainty principle, turned out to be correct — and it had a major implication: It placed a fundamental restriction on how precisely time could be tracked.

Every clock in human history has operated conceptually the same: it references some naturally occurring frequency as the basis for its "tick," which defines the passage of a unit of time. Clocks have historically been far too imprecise for the Heisenberg limit to affect uncertainty in their frequencies — until December of 2020 when a group of MIT physicists announced they had broken past a major hurdle in the pursuit of ultra-precise timekeeping, putting the Heisenberg limit in sight.

Humans have practiced timekeeping since the dawn of humanity. From following the periodic movement of the stars and sun to mechanical clocks based on the swing of a pendulum to modern electrical crystal clocks that use the natural vibrational frequency of quartz, humans have constantly battled the universe's inherent uncertainty and chaos [IK1] to increase the precision of timekeeping. By the time Einstein was alive and debating quantum mechanics, humans had whittled down uncertainty in timekeeping to the drift of one second every other day. Yet this is not precise enough for many modern applications, including space missions, GPS technology, the keeping of the international time standard, and cutting-edge physics experiments. This precision came with the atomic clock.

When atoms transition from an excited higher-energy state to a lower-energy state, they emit a particle of light with a frequency tied solely to fundamental universal constants. For this reason, physicists refer to this atomic light frequency as the "ideal standard" for timekeeping. The motivating goal of atomic clocks is to utilize this frequency as its standard. They achieve this by probing a group of atoms using a laser with a frequency close to that of the atom's light frequency. The atoms react by releasing this light, which the clock then references to guess the frequency again with the laser, repeating the cycle. The atomic frequency drives the tick of the clock.



However, when probing a group of atoms, uncertainty soars above the theoretical Heisenberg limit as all the atoms act independently of each other. Known as the "standard quantum limit," the MIT physicists have overcome this final hurdle by successfully implementing a proposed technique that squeezes the atomic states. When performed on the entire group, the atoms become dependent on one another and entangled, collapsing uncertainty down to the fundamental Heisenberg limit.

The group reported uncertainty measurements only 1.9 times greater than the Heisenberg limit, a figure signifying an unprecedented precision in the tracking of time. As measurement sophistication continues to increase and non-fundamental uncertainties in measurement methods no longer dominate, the precision of time measurements asymptotically approaches the theoretical Heisenberg limit as these clocks are left running for longer periods.

The applications for this new technology are far-reaching. This level of precision is encouraging for some of physics' most notorious modern-day challenges, including the search for gravitational waves at large observatories like MIT and Caltech's Laser Interferometer Gravitational-Wave Observatory, or LIGO. Northeastern physics professor and former LIGO researcher Dr. Alessandra Di Credico explains, atomic clocks allow gravitational-wave scientists to "combine the arrival times of different signals coming from independent interferometers placed on the Earth's surface" creating the capability to triangulate these readings and pinpoint their origin. She adds, researchers can then "compare the arrival time of such a signal with other experiments such as space-based telescopes, detectors of EM radiation, or Earth-based neutrino detectors."

This technique was first demonstrated in 2017 by two independent gravitational wave groups, LIGO in the United States and Virgo in Italy, with the detection of waves from two stars death-spiraling into an energetic collision. Through comparing atomic clock measurements, they succeeded in triangulating the location of the event in the sky and confirming the observation with dozens of Earth and space telescopes that witnessed the merger. Similar applications for ultra-precise atomic clocks exist throughout physics — from "dark matter" to fundamental particle physics research — bestowing physicists with an arsenal of new tools to probe the mysteries of the cosmos further than ever before.

*Nature* (2020). DOI: 10.1038/s41586-020-3006-1
*Reviews of Modern Physics* (2015). DOI: 10.1103/RevModPhys.87.637
*Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.161101

PHOTO BY SHUTTERSTOCK

# Thermal insulation through optimum disorder

BY JASON DENONCOURT,
CHEMICAL ENGINEERING & BIOCHEMISTRY, 2023

**The fundamental principles of thermal conduction are outlined by Fourier's Law.** This law states that the rate of heat transfer via conduction through a material is directly proportional to that material's thermal conductivity (k), cross-sectional area, and temperature gradient. Just as a pressure gradient is the driving force behind any fluid transport, a temperature gradient, or differences in temperature at varying positions within the material, is the primary driving force behind heat transport. The cross-section area is considered for all three dimensions — x, y, and z. Additionally, more complex heat transport processes are not at steady-state, where the temperature gradient varies with time due to accumulation or depletion. For non-steady-state systems, the problem-solving becomes more complex, as time acts as a fourth dependent variable.

The final consideration of Fourier's Law is thermal conductivity. This is an experimentally determined value that varies depending on the material. Efficient thermal conductors, such as metals, will have a high thermal conductivity and are widely used in heat sink applications and other scenarios where rapid heat transfer is desirable. Conversely, poor thermal conductors, such as plastics and ceramics, are widely used as thermal insulators, for a wide range of applications from residential wall insulation to electronics.

Thermal conductivities are influenced by several different factors, including temperature, chemical phase, and structure. As previously mentioned, conduction can occur in the three primary phases of matter: solid, liquid, and vapor. In general, solids have better thermal conductivities than liquids, which have better thermal conductivities than vapors. In the absence of convection, air and most other gaseous mixtures are effective insulators. This is because conductive heat transfer is due to molecular interactions. The greater the space between molecules, as vapors have lower densities, the longer it takes for energy to be transferred between molecules and particles. Similarly, lattice structures in some solids help to transfer thermal energy more efficiently. In other words, lattice structures create convenient, direct paths of heat transfer, while disordered structures force heat to travel along circuitous paths.

Scientists at the University of Bayreuth are researching how different degrees of disorder influence the thermal conductivity of nanoparticle powders. The primary consideration for their research is concerned with molecular configuration and structure. Ultimately, scientists were able to determine how the thermal conductivity of a powder is influenced by chaotic configurations.

The first nanoparticle the researchers explored were photonic crystals. These crystals, which are responsible for the glitter appearance on butterflies, are naturally produced by insects but can also be synthesized easily in the lab. The result is very fine and regularly shaped, and collectively possesses a stable structure. These particles, even in an ordered arrangement, have a very low thermal conductivity.

Any order in the nanoparticles or any material is associated with higher thermal conductivity. Therefore, the scientists set out to disorder the organized structure of the powder to see if they could manifest a lower thermal conductivity. In photonic crystals (ordered configuration), each particle has roughly 12 other particles in its immediate vicinity. The scientists would therefore have to vary this metric of order to generate the disorder. The greater the disorder the more indirect of a pathway heat will need to take in order to traverse the same distance.

To make the powder more difficult to thermally permeate, the scientists employed both laboratory experiments and computational simulations to mimic potential configuration. Analytical techniques, like scanning electron microscopy (SEM), UV-vis, and optical microscopy, were used to experimentally determine the structures, and the computational technology enabled the researchers to examine in detail several different ways to decrease thermal conductivity. Ultimately, the scientists determined that the best way to generate disorder and improve thermal insulation would be to create a mixture of different sized particles. More specifically, they concluded that a binary mixture of mostly small particles with some larger particles would be an appropriate, reproducible method to generate chaos. In fact, the scientists were able to conclude that the disorder was able to decrease the thermal conductivity of the photonic particles by upwards of 50 percent in comparison to the crystallized, ordered configuration.

It sounds sort of strange to be able to reproduce chaos, but this is key to any scientific process and has several relevant industrial applications. Several fields from manufacturing to computers rely on heat transport specifically even at the micro to nano level to generate safe and effective products. This study certainly provides insight and clarity into the fundamental properties governing heat transport.

*Advanced Materials* (2018). DOI: 10.1002/adma.201704910

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022
PHOTO BY GUS MUELLER, MECHANICAL ENGINEERING, 2023

# NEFARIOUS NOTIFICATION

## SOCIAL MEDIA ALGORITHMS AND HOW THEY DRIVE US

BY SHELLEY JEON, PHARMACY, 2025

DESIGN BY YECHAN YANG, BIOLOGY & PSYCHOLOGY, 2022

**The average person has 35 apps installed on their phone and spends over two hours per day on social networks.** When social media originally took off in the early 2000s, its purpose was for users to connect with friends and family, share positive moments, and seek interesting information about the world. Today, social media platforms like Facebook and Instagram provide endless reels of curated content, on-demand information, and emotional connection. Over the past two decades, these platforms have undergone a dangerous paradigm shift: They are in a race for human attention.

It is now an oversimplification to say that TikTok, Youtube, and Twitter make money merely through advertisements. More accurately, these platforms profit from user engagement, essentially striving for the greatest proportion of the user's screen time. How often people search for something, stare at a photo, what users save for later — these are the metrics, the big data, that technology companies and advertisers are truly after. The basic premise of big data is that its sheer volume guarantees a statistically precise model every time. Social media companies use big data analytics to make increasingly accurate predictions of user behavior, such as the next Youtube video that will keep a user glued to their screen or the next pair of shoes that is eagerly added to their cart.

Even the most self-aware technology users can fall prey to this type of artificial intelligence, which can identify patterns in personal usage data to understand users better than they understand themselves. By knowing user preferences so well, machine learning algorithms are able to present advertisements that are statistically extremely likely to elicit user engagement, whether that entails liking a post, making a purchase, or sharing content with friends.

Not only do technology companies leverage personal data, but they are designed in a way to keep users on the platform, effectively churning out more and more information about them. To boost screen time, social media exploits human psychology in many subtle and conspicuous ways from subliminal updates to high-energy clickbaits. For instance, the "refresh" function available on virtually every social media provides users with the potential for instant gratification, such as through an image of someone attractive or a highly anticipated message. Psychologists refer to this type of reward delivery as positive intermittent reinforcement, and it occupies the same neural circuitry as casino slot machines. Like with gambling, users are not rewarded with every refresh or notification check — this is predictable and not exciting. Rather, the unexpected and sporadic nature of social media triggers a much greater positive response in reward centers of the brain.

There are both personal and societal consequences of such chaotic interactions between the brain and social media. Generation Z, the first generation to grow up with technology from middle school, is reported to be more anxious, depressed, and likely to experience suicidal ideation. Furthermore, the illusion of perfection is easily enabled by editing features in social media, which promotes the pursuit of unrealistic appearance ideals and self-comparison to peers. Technology platforms have also fueled global issues such as political polarization, election fraud, and fake news. For instance, in 2016, Twitter and Instagram joined Facebook and Youtube in abandoning chronologically ordered feeds, instead replacing them with an algorithm that places the most profitable (i.e., attention-grabbing) content at the top of the feed. Not only did this update maximize content from close friends, it also prioritized other captivating content such as clickbait and conspiracy theories. Because the algorithm selects content that best aligns with an individual's personal data, users were insidiously pushed into their own filtered, polarized worlds.

Individuals can minimize the emotional consequences of social media by using it as minimally and consciously as possible. Uninstalling apps, turning off notifications, and installing browser extensions to remove personalized recommendations are excellent ways to rewire the neural circuitry shaped by excessive social media use. Individuals can also be instigators of rejecting misinformation by fact-checking before sharing something online and avoiding clickbait. Actively seeking opposing perspectives, such as through following people who you disagree with, is also an effective method to avoid entering a polarized bubble.

In less than two decades after the advent of Facebook, social media has dangerously proliferated into an agonist for loneliness, distraction, polarization, and misinformation. It must be recognized that the design of technology platforms enables this type of behavior and that, before we see a long-term shift towards more ethical technology, individuals are largely responsible for managing the role of social media in their lives.

*Int J Environ Res Public Health* (2019). DOI: 10.3390/ijerph16142612
*Clinical Psychological Science* (2017). DOI: 10.1177/2167702617723376

# TO FEAR OR NOT TO FEAR: ROBOTS

BY NETHRA IYER, CHEMICAL ENGINEERING, 2024

**In 2018**, Quantic Dream and Sony Interactive Entertainment developed a game with over 100 pages of script and months of filming: "Detroit: Become Human." The year is 2038, and androids are being used by humans all throughout the United States. However, following the lives and growth of three androids, players start to realize that these robots are not merely machines — they can feel emotions from anger to love and they deserve equal rights. Although this game is full of action and takes inspiration from past revolutions for freedom, it still has an underlying question: what if androids really do come to exist in the future and what will happen?

Before actually understanding the effects of machines in the future, it is important to look at when and how machines will ultimately rise to power.

The concept of a machine relates to the idea of the technological singularity. According to the video "The Technological Singularity" by Aperture, the technological singularity is the "tipping point when technological progress is so overwhelming that [humans] will no longer be in control of it or the things that it will lead to." Also called the technological explosion, Moore's law states that "computing power tends to approximately double every two years," which leads scientists to believe that the approximate date of the singularity is between 2040 and 2050. At this point, technology will have surpassed the intelligence of the human brain. Machines will be able to perform non-repetitive tasks in a matter of seconds that require years of training for humans. This cycle will then continue, as predicted by British mathematician Irving John Good in his 1965 paper "Speculations Concerning the First Ultraintelligent Machine." According to Good, the machine is intelligent enough to "gradually improve itself out of all recognition, by acquiring new equipment." This means that humans will no longer invent or research, as the machine known as the Seed AI can keep reprogramming itself to become better than its predecessor. All the machine will need is equipment, which humans will initially provide until the machine figures out a way to do so on its own.

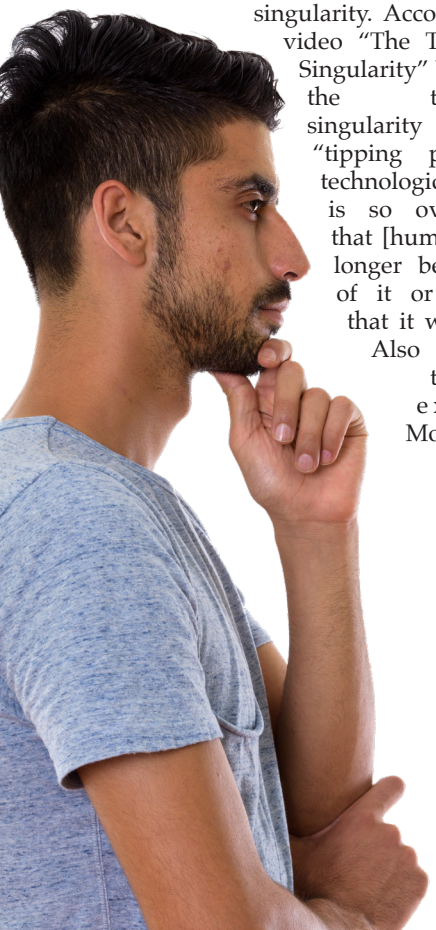
This leads to the intriguing yet worrisome idea that has filled the minds of scientists and writers alike: evil robots. Will robots understand their intelligence and suddenly turn on their creators?

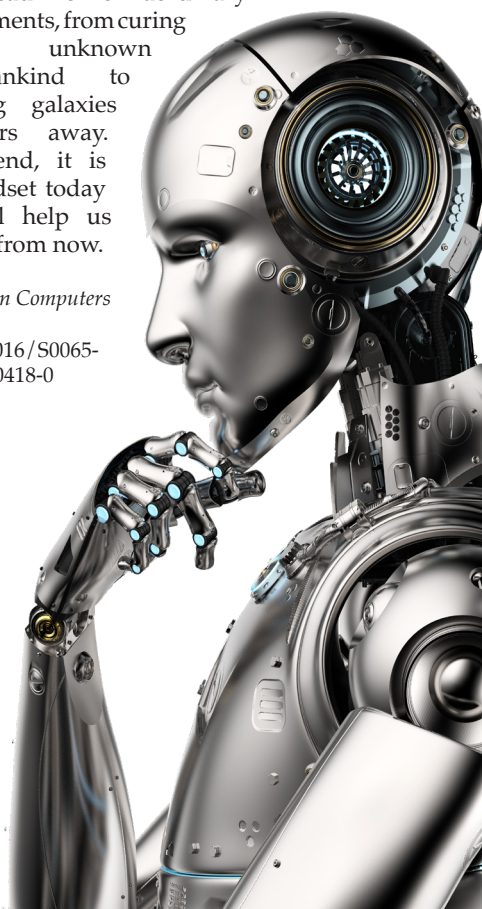
The short answer is no.

The long answer is it is very unlikely due to one reason: chaos. The universe and nature itself are extremely unpredictable. The second law of thermodynamics states that the entropy or randomness of the universe is always increasing. This means that after a certain extent, it will be impossible for any super intelligent being to "improve its predictions of the future and […] increase in intelligence." This comforting idea could be turned on its head by questioning whether or not the perceived chaos of the universe is merely a farce which robots in the future could then use to exploit humans; however, based on the current research and level of machines, the chances of this occurring are pretty rare.

As humans, it is our job to ensure that no matter what, we are prepared for the future. If, by any chance, we reach a stage as depicted in "Detroit: Become Human," we will need to know what is to be done and how these two entities — robots and humans — can coexist. Preparation does not mean gearing up for battle. Rather, it is embracing "the potential of augmentation" and having a positive outlook. Robots in the future could lead to extraordinary developments, from curing diseases unknown to mankind to exploring galaxies light-years away. In the end, it is our mindset today that will help us decades from now.

*Advances in Computers* (1965).
DOI: 10.1016/S0065-2458(08)60418-0





DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

PHOTOS BY SHUTTERSTOCK

# CHAOS THEORY AND MACHINE LEARNING

BY DINA ZEMLYANKER, DATA SCIENCE & BIOCHEMISTRY, 2024

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

**Chaos theory says that even the most seemingly random processes can actually be described and predicted using a set of complex mathematical equations.** The original equation used to define chaotic activity is the Kuramoto-Sivashinsky equation, which models propagating flames. Using this equation, one can model the chaotic elements of many different processes. For example, in long-term weather prediction, a version of this equation can describe the pattern by which rogue waves and earthquakes occur. In the same way that the Kuramoto-Sivashinsky equation is a giant step in the right direction for solving these seemingly impossible problems, as with most disciplines today, machine learning (ML) has proven to be an invaluable addition to the study of chaos theory.

A machine learning model is an analytical tool capable of generating knowledgeable predictions for new inputs. The practice of using ML models in place of equations to determine chaos can be exemplified by weather prediction. Instead of predicting weather using a complex mathematical system to represent various components of the atmosphere, an ML model determines its own complex, "invisible" rules based on subtle patterns in the data.

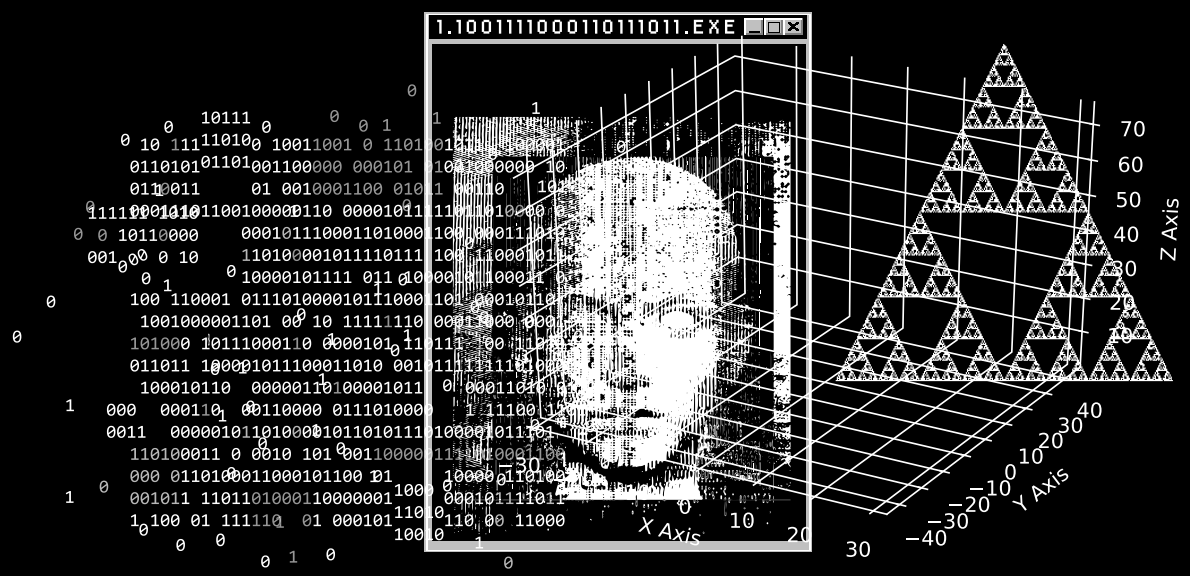
One way to combine ML models with equations for chaos theory solving is to train an ML model on solution data obtained from the Kuramoto-Sivashinsky equation. To generate predictions with greater accuracy, the ML model learns patterns in the data and uses these "invisible rules" to produce more accurate solutions to the chaos problem. The original application of this combination was to predict movement of propagating flames. However, the combination of ML models and chaos theory equations can be applied to any long-term prediction task, including predicting fashion trends, weather, or music.

An important characteristic of ML models used in conjunction with equations is the incorporation of reservoir computing. Reservoir computing is the idea of mapping input signals to a higher dimensional computation system using a non-linearity, which is any function that does not follow a linear or direct relation pattern. A human example of reservoir computing is when context words are used to determine the meaning of an unfamiliar word. Instead of using only the characters in the given word, humans will consider the known words around the given word to determine the meaning.

In chaos theory, prediction time, which is the distance into the future a model can predict, is measured in a unit called Lyapunov time, or the amount of time it takes for two near-identical states in a chaotic system to exponentially diverge. Using a reservoir computing ML model in conjunction with the Kuramoto-Sivashinsky equation, chaos theorists at the University of Maryland were able to predict eight Lyapunov times into the future for a model predicting movement of propagating flames. This means that this model was able to predict eight times farther into the future than any other method.

The benefits to using chaos theory with the coupled use of chaos theory equations and machine learning are numerous and span across almost all disciplines. Machine learning modeling of chaos can be used for nearly any long range prediction task, which has applications in social science, healthcare and almost every other discipline. A well-developed chaos model can facilitate long-term weather prediction models, help treat sleep disorders and heart disease, and even be used for music production to predict the best next notes of the song. Machine learning modeling of chaos can monitor a heart for an impending heart attack and, in combination with medical devices, send impulses to the heart to prevent arrhythmia. Combining the historical "rule-based" mathematical systems with the rapidly developing field of machine learning has led to an increase in accuracy of the prediction of chaos and, as the field advances further, has the potential to benefit a wide variety of disciplines.

PHOTO BY SHUTTERSTOCK




*Chaos* (2018), DOI: 10.1063/1.5028373
*ArXiv* (2020). Preprint: 2003.01771v2 [cs.GL]
*2019 Global Conference for Advancement in Technology (GCAT)* (2019). DOI:10.1109/GCAT47503.2019.8978360

# ON THE ORIGIN OF LANGUAGES:

## Our Proto-Indo-European roots

BY ANANYA IYENGAR, BIOLOGY, 2023
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022


**At first glance,** the English, Hindi, Russian, and German languages seem quite different from one another. They use seemingly unique sounds, letters, and ways of translating ideas into words. Thus, it may come as a surprise to learn that these languages are all descended, so to speak, from a common ancestor, much like all the biological species of the world. Unlike biological evolution, however, all languages did not descend from one ancestral language. Rather, there are a number of language trees, each giving rise to dozens, or even hundreds, of daughter languages.

The most fruitful of these trees is Proto-Indo-European (PIE), the ancient language from which around 445 contemporary languages evolved. PIE has been dead for thousands of years without a written record, so much of the language experts have reconstructed is an approximation. But how did the quest for this common ancestor begin? In the late-16th century, globalization and imperialism brought Europeans all over the world and scholars visiting the Indian subcontinent observed similarities between the lexicons of Indian and European languages. During the 1580s, Filippo Sassetti, a Florentine merchant, noted several Sanskrit words that sounded familiar to his Italian-trained ear, such as the word for "God" which is *devaḥ* in Sanskrit and *dio* in Italian. Other notable examples are serpent (*sarpaḥ*/*serpe*) and nine (*nava*/*nove*). While the words are hardly identical, the similarity is indisputable.

The hypothesis of a shared ancestor grew slowly and, in 1786, prominent philologist Sir William Jones presented his ideas at a lecture, stating that "no philologer could examine them all three [Sanskrit, Greek, and Latin], without believing them to have sprung from some common source, which, perhaps, no longer exists." Recently, researchers have traced back the Indo-European family's divergence to recreate the vocabulary and structure of that "common source." When experts observe a phonetic similarity between words of several modern Indo-European languages, and the meaning of the words is the same, they attribute it to a common ancestor. Experts do not use false cognates, or words that sound similar between languages but do not carry the same meaning.

Despite over a century of research, there is still no universally accepted theory for *how* exactly PIE evolved into hundreds of daughter languages. The general hypothesis is that the Proto-Indo-Europeans traveled to new places, taking their language with them. The language then evolved into daughter languages based on newfound people, environment, and culture. The broad schema of language divergence is not very different from biological evolution, specifically the idea that geographic isolation leads to the proliferation of distinctly new but traceable traits. In this case, linguistic changes within the isolated population are analogous to biological traits. However, disagreements stem from inconclusive evidence of the origin of the Proto-Indo-Europeans and the patterns in which they traveled.

The frontrunning theories place the linguistic homeland, or *Urheimat*, in either Anatolia (modern-day Turkey) or the area roughly between the Black and Caspian seas known as the Pontic-Caspian Steppe. The Steppe hypothesis theorizes that the Proto-Indo-Europeans were an invasive tribe that spread its language by overtaking other settlements. Archeological discoveries, as well as haplotype genetics, may support this hypothesis. Haplotypes are groups of genetic variants that are inherited together. The R1a1 haplotype is commonly found in Poland, Russia, and Ukraine, as well as occasionally in Central Asia, Afghanistan, Pakistan, and India. This distribution supports the geographical spread proposed by the Steppe hypothesis. The competing Anatolian hypothesis, credited to the scholar Colin Renfrew, ties the spread of PIE to the peaceful Neolithic spread of agriculture from the Fertile Crescent. The Anatolian theory is also supported by archeology and linguistic reconstruction but lacks the convincing support of DNA analyses associated with the Steppe hypothesis.

As modern science and technology improve, more evidence will likely emerge to support one theory or another or even give rise to an entirely new hypothesis. We may never conclusively know the origin of many modern languages, but what we know already gives us valuable insight into our interconnected history. Even cultures as different from each other as Italian and Afghani are tied together by the origins of their languages. We learned of our shared biological ancestry quite some time ago, but it has often failed to unite us. Perhaps one day, the common ancient origin of our languages, which is tied inextricably to our cultures, will be enough to overcome our modern differences.

*European Journal of Human Genetics* (2015).
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# POST-TRUTH POLITICS AND THE FUTURE STATE OF KNOWLEDGE

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**The 2016 presidential election and victory of Donald Trump marked the start of a period scholars call the "post-truth" era.** While this concept isn't new, a post-truth society is characterized by the absence of shared objective standards for truth in favor of appeals to emotion or personal beliefs. Today, many politicians appeal to the emotional impulses of their voter bases, going so far as to reject expertise, rationality, and fact. This epistemic shift in the public discourse has politicized science, but it would be a mistake to assume that science was ever apolitical. Despite the satisfying notion that facts and objective truth eclipse subjectivity and personal biases, the reality is that empirical evidence means nothing without the power we give it to be an authority. This is because the very ways by which we acquire experimental knowledge have been weaponized in the public discourse to diminish its authority.

One of the most compelling means of acquiring knowledge is empiricism, the foundation of the scientific method. Enlightenment philosophers prized the belief that objective truth exists outside of the subjective self and the importance of individual freedom and expression, and these ideals still maintain influence. However, there is a tension between the equality of individual expression and the power that scientists and experts have over the public in establishing knowledge.

The public must defer all the power to create knowledge to experts, but there's often a disconnect in that creation process. Experts are aware that knowledge is tentative and develops over time — studies make conclusions from observed evidence, scientists peer review those studies, and subsequent experiments validate those conclusions. However, when this discourse is translated into the language of the public, the jargon that characterizes the conclusions also changes. What scientists call statistically significant, the public might call fact, and the label of "fact" ends debate. Therefore, when that fact is proven wrong — that is, a conclusion is corrected by more evidence — it destabilizes the legitimacy of expertise.

This brings us to the power problem of expertise. Expertise has a monopoly on facts, and discussions about knowledge face a dichotomization between fact and opinion. Knowledge and facts from experts are deemed "rational," and that classification creates the foil of "opinions" of non-experts as "irrational" or "ignorant," delegitimizing the voices of non-experts. The appeal to expertise is thus a political and rhetorical tool for effectively ending debates because of the asymmetry of power between experts and the public. Appealing to expertise might be premised on the rigor and refinement of knowledge that come with years of experience, but rhetorically, it nullifies discourse. Within this hierarchy of acceptable knowledge, we prize rationality and fact over opinion, emotion, and irrationality — expertise over public "opinion." Because the public has no means to establish their legitimacy, they expect experts to be infallible, but when experts fail to meet those impossible expectations or when they're on the opposing side of an issue, they're blamed and criticized more heavily. This rupture in expectation takes valid, critical skepticism to another level, from reasonable

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caution to outright rejection. Because experts tend to align more to the political left, expertise thus has a perceived political position, and accepting or rejecting expertise becomes political. The rise in partisan think tanks and special-interest group research has resulted in the exploitation of this scholarly discourse, granting bad actors the title of expert and legitimizing the relatively powerless detractors of left-wing experts. Science is not always final, but simultaneously, that's precisely the reason dissenting opinions and "alternative facts" can have legitimacy — because people are willing to give power to those "facts" over the other side's.

We don't have to look further than the COVID-19 pandemic to see the ousting of experts by the political right. Dr. Anthony Fauci, director of the U.S. National Institute of Allergy and Infectious Diseases, has had a decorated career as a public health official but was criticized by Republicans for changing his stance on mask wearing towards the beginning of the pandemic after new data suggested that wearing masks could effectively mitigate community spread of the coronavirus. To many Republicans, this was proof that he lacked the credibility to make public health recommendations, and they saw this as a dishonest attempt to further partisan objectives, especially since the political left largely and readily accepted the mask and public health guidelines. In this particular scenario, Dr. Fauci made two honest mistakes — being a faithful practitioner of his profession and being associated with the left.

We trust experts like Dr. Fauci because we cannot attain the same proficiency in every field. However, when we feel betrayed by or skeptical of the authorities of information, we tend to seek out sources that we do trust because they feel right and make sense to our worldview. Knowledge always comes with a tint of subjectivity and perspective, but when we take that to be grounds for complete dismissal, we're overcorrecting and dismissing any opportunity for consensus. There's no simple solution to achieve future consensus and reconcile a divided, post-truth society, but any analysis of the issue must first recognize the power structures that shape our discourse of knowledge and policy.

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# FAREWELL AND ALL THE BEST!

## KRISTI BUI
PRESIDENT

Computer science major Kristi has been a member of *NU Sci* for all of her college career as a designer, head of design, and finally president. She loved the amount of creativity and collaboration that comes with producing each issue, and will especially miss the emotional updates at e-board meetings. After graduation, Kristi will work as a software engineer in the finance industry in New York City.

## SARA GANNON
EDITOR

As a writer for the last four years and an editor for the last two, it is hard for Sara to imagine parting ways with *NU Sci*. She has had a wonderful time working with the talented team of editors and writers, who have always fostered a sense of support, creativity, and enthusiasm for writing that was an indispensable part of her time at Northeastern. After graduation, Sara will be heading to Duke University to start her PhD in Neurobiology.

## JENNIFER GARLAND
EDITOR

From 2017 to 2021, Jennifer has been a writer, editor, and designer for *NU Sci*. She is majoring in applied physics and math and has enjoyed conducting interviews for articles and learning about different areas of science. This fall, Jennifer will begin a PhD in applied physics/materials science at Northwestern University.

Goodbyes are never easy, but NU Sci is beyond proud to present to you the class of 2021. While their last year may not have been spent in their classrooms or labs, they've been stellar members of the magazine throughout all their years here. We wish them nothing but the best, and we have the utmost confidence that they're moving on to even more phenomenal things. They've profoundly influenced us as both a publication and as people, and we will always be grateful for them. For now, let's take a moment to reminisce about their time with us and congratulate them for what they have planned for the future.

## ANSON HUANG
WEBMASTER

Freshman year, Anson joined *NU Sci's* webteam and has stayed with it for all four of his years at Northeastern. His favorite part of being on webteam is being able to read all our writers' articles as they get posted on the website! While he'll be missing the friends he's made at Northeastern and *NU Sci*, he's very excited to continue his education this fall at Yale, pursuing a PhD in chemistry.

## BEIYU (PAM) LIN
EDITOR

Biology major Beiyu (Pam) Lin has been a writer and editor for *NU Sci* for the past three years. She has been able to creatively explore her different interests within science through the magazine alongside an incredibly welcoming team. After she graduates, she plans to work in life science consulting and eventually pursue graduate school.

## YAEL LISSACK
HEAD OF OUTREACH

To be welcomed into a community of passionate, curious people has deeply enriched both Yael's college experience and character. *NU Sci* has given her the opportunity to explore ideas beyond the confines of her major and for this she is exceedingly grateful. She will cherish the connections she's made as head of outreach and will miss it very much. She is not quite sure what her future holds — onwards toward the next adventure!

## YASMINE MYFTIJA
EDITOR

During her time at Northeastern, Yasmine Myftija has thoroughly enjoyed her time as a writer and editor for NU Sci. As a biology major, she has especially enjoyed spreading impactful scientific information through the pieces she's written and edited alike. After graduation, Yasmine will continue to work as an EMT at Fallon Ambulance Service and hopes to one day have a career in medicine as a trauma surgeon.

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