

ISSUE 47 Spring 2021

NU SCI



Bloom

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LETTER FROM THE EDITOR

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Negative change almost always seems to sneak up on us, but when it happens, it feels like this sudden shift, an abrupt interruption to the regular flow of things. The collapse happens in an instant, and the crumbling is palpable. Suddenly, we have to change lest we fall too.

In a similar sense, positive change is imperceptible. It sneaks up on us too, but we never see it until something bad happens or until we take a moment to breathe in the crisp air and reflect. Suddenly, we're not at rock bottom anymore, and we can see that even the seemingly mundane efforts we took to carve our way out, well, they worked.

A flower can be uprooted in a second, but the same flower takes a whole season to bloom from a seed. A star can collapse in a fraction of a second, but it takes millions of years to form. It's the principle of time that permits creation, growth, and prosperity. Unfortunately for us, we don't have millions of years; our time is limited. However, the fundamentals to flourishing are still the same — time, of course, and persistence. These natural processes all have an innate rhythm, a continuous pursuit to their climax. And naturally, they'll face unanticipated challenges along the way, but no flower reverts back into a seed. A seedling does not focus on becoming a flower; rather, it focuses on surviving a sudden frost or an unforgiving storm. The same is true for us. While we do have the capacity to regress, our progress comes from our ability to focus on the *present*, not to be *prescient*. And even though these efforts in the moment might seem fruitless, they require hindsight to be fully realized, and only after that can we see our bloom.

So when the weather gets warmer and you see that first flower proudly displaying its petals, it might seem like it happened overnight, but don't forget that it took a long and incremental journey to get there. And when we acknowledge the minutiae of the sublime and the good all around us, we remind ourselves that our own blooms are only a matter of time.

In the meantime, please take a moment to enjoy seeing our members and their talents flourish in "Bloom."



A handwritten signature in black ink that reads "Binh Dang".

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Recap of Springer Nature science journalism panel

BY YAEL LISSACK, BIOENGINEERING, 2021

On December 1, 2020, *NU Sci* hosted a science journalism panel with guests from Springer Nature who came from a range of positions within the company and provided valuable wisdom to the attendees. Here are some abridged highlights from our conversation.

The panelists

Jill Tietjen



Dr. Amin Fatemi



Jill Tietjen is an electrical engineer who has served as the CEO of the National Women's Hall of Fame. She is a worldwide advocate for telling women's stories and writing women into history.

Dr. Amin Fatemi is the Managing Editor of the Mathematics, Physical and Applied Sciences, and Engineering sections of *Springer Nature Applied Sciences* journal.

Yael Lissack: How did you arrive at this point in your career and what specifically influenced you to join your field?

Mohammed: "When I graduated, I dabbled with many different things. We didn't have any majors in Egypt that focused on science journalism. One thing that eventually made me stay in this field is that this work is a force for good. We are able to increase science knowledge and bring access to science to the average person."

Swati: "What made me stay is the ability to make a difference and to interact with some of the brightest minds in the world."

YL: How often do people move into the field of scientific journalism or publishing from research and what does that process look like?

Mohammed: "One of the questions we dabble with a lot is should a science journalist have a science background or a journalism background?" And I've seen people come from both — I don't think there's a preference. It's really about bringing the passion. I do find that my science background helps a lot, at least when I'm talking to scientists about the questions I ask. But there is another argument which I think

is very interesting: If you go in knowing very little about a topic, you ask the right questions. You can ask questions which a more experienced person would overlook. I've seen a lot of people move from research into science journalism. It's extremely feasible."

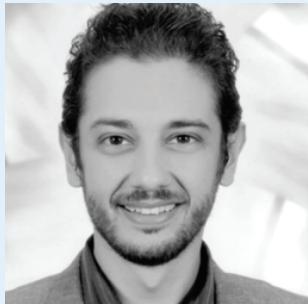
YL: What advice would you give to someone who's looking to get started in a career of science writing, journalism, or publishing?

Jill: "When you write about something that you're passionate about, that's when you have the opportunity to get published."

Swati: "As an aspiring writer who has not started writing yet, I would recommend that if you want to write, just start writing — don't worry about getting published ... Start writing articles and posting them online and the career and the publishing will find you."

Mohammed: "The really good thing right now is that so many of the barriers that there were in the past have been removed. You can just set up your own blog right which can help you build up a portfolio that you can show to potential editors."

Mohammed Yahia



Mohammed Yahia is the executive editor of Nature Research in the Middle East.

Nathalie Jacobs



Nathalie Jacobs [has] worked at Springer for 20 years, always in Engineering. As of 2019 [she is] the Project Manager for the Springer Nature Interdisciplinary Journal *SN Applied Sciences*.

Swati Meherishi



Swati Meherishi leads the Asia Pacific books program for Engineering and Applied Sciences.

Mary James



Mary James [is] an acquisitions editor for scientific books in communications engineering, signal processing, and optical networking.

YL: Do you ever deal with work that's not within your scope of expertise, and if so, how do you prepare yourself to have the tools to edit and publish such work?

Swati: "It's mostly about relying on experts to give you the right advice and to make sure that we have the right network of experts who can validate the work that we're publishing."

Mary: "Everything goes through a peer review process and that's where the technical expertise comes in. It's a pretty rigorous process where we make sure it's all scientifically sound."

Mohammed: "When I start a story that I have absolutely no idea about, besides doing a lot of reading and researching, I have a strong network of researchers who I know I can turn to. Sometimes it's scary to ask stupid questions ... but you just have that have the confidence to ask questions no matter how stupid they might sound ... if I don't understand something, then my readers probably don't either."

YL: What's the best piece of advice you've ever gotten?

Nathalie: "Be yourself and that's how you progress ... Be honest, and people will appreciate that. Editors-in-chief and

scientists only appreciate it if you are honest with them — that's my main advice."

Swati: "My first boss told me, in my first week, to never say no to anything, especially when you're starting out, because that's how you learn ... Learning things early on is crucial. Don't just say 'oh that's not my job so I'm not going to worry about it.' Try to learn what others do."

Mary: "Academic publishing is a small industry. it's good not only to not hold grudges but also to not burn bridges because your assistant might be your boss one day."

YL: How has the ongoing pandemic affected your work?

Mohammed: "In a way, we have been training all our lives for this. It's really become the most important year to better communicate science. There is so much misinformation out there, so at this critical time we're able to counter it and provide this really important service to people."

See our website for the complete interviews and more information about the panelists.

HIDDEN MARKOV MODELS FOR BIOCHEMICAL APPLICATIONS

BY DINA ZEMLYANKER, DATA SCIENCE & BIOCHEMISTRY, 2024

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

As the amount of data in the biological field expands exponentially as a result of more efficient biological processes, such as Next Gen Sequencing, machine learning has become a tool to leverage this data for contributions to the drug development and medicinal fields. One of the most widely utilized machine learning models is the Hidden Markov Model (HMM).

HMMs are based on Markov chains, a mathematical system that illustrates the probabilities of transitions between states. For example, in a Markov model describing weather, it could have two states: rainy and sunny. The Markov model would show the probability that given that today was rainy, tomorrow is sunny and vice versa. In HMMs, there is an added complication called observables. These are useful when directly seeing whether it is sunny or rainy is impossible, making these states "invisible." For example, for an HMM predicting the weather, the invisible states would be rainy and sunny, and the observations could be what people outside are wearing. In simpler terms, the model could predict which days in a week will be rainy and which will be sunny based on people's outfits.

To determine the sequence of states, researchers use the probability of seeing each observable given a certain invisible state, known as the emission probability. The collection of all of these probabilities is called the emission probability matrix, while all transition probabilities between states are called the transition probability matrix. These two matrices are combined to determine the probability of the next invisible state.

For a protein predicting HMM, the invisible states can be the exons and introns. Exons are the

regions of RNA that code for proteins and introns are the non-coding regions. For every state in the model, there is a different set of emission probabilities based on the observable qualities of each exon and intron. There are multiple uses to this kind of HMM. The first way to use this would be computing whether or not the sequence is coding, which means that it contains the instructions

recursively finding the maximum probability of one latent state following another latent state, given the observables.

Out of the plethora of biological applications of HMMs, the most useful have proven to be modeling characteristics of protein families, such as globins and kinases, to help classify new proteins into different protein families. This allows researchers to infer qualities and find multiple sequence alignments, which are when proteins are compared by sequence and assigned a similarity score. The most popular implementation of this is the Sequence Alignment and Modeling System (SAM), which is used for multi-protein sequence alignment and profiling using HMMs. Another essential application of HMMs is in protein structure prediction, where the protein structure is determined using both an HMM and an unfamiliar protein sequence; this has proven to be very useful in drug development and medicine.

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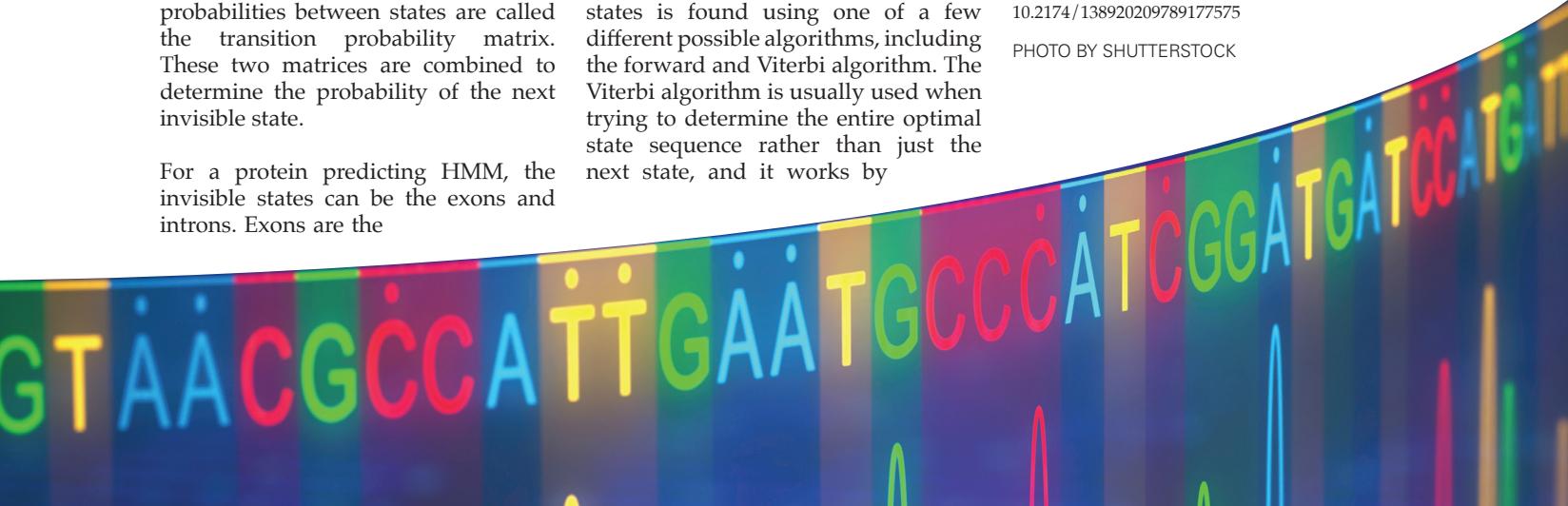
to create a protein. Another way would be to predict the locations of exons and introns given that it codes for a protein. For this process, the states would first be predicted using the observables. After predicting the optimal sequence of states, it will be clear which codons belong to which exon or intron based on their locations.

The optimal path or sequence of latent states is found using one of a few different possible algorithms, including the forward and Viterbi algorithm. The Viterbi algorithm is usually used when trying to determine the entire optimal state sequence rather than just the next state, and it works by

Knowing the properties and shapes of proteins, drugs can be created to ameliorate their negative effects by making changes to their structures and interrupting their processes. With the help of HMMs, scientists can develop new medicines much more cheaply and quickly.

Genomics, Proteomics & Bioinformatics (2004). DOI: 10.1016/S1672-0229(04)02014-5
Curr Genomics. (2009). DOI: 10.2174/138920209789177575

PHOTO BY SHUTTERSTOCK



THE GOLDEN RATIO:

Myth or magic of mathematics?



BY LOUISE HOLWAY, ARCHITECTURE & CIVIL ENGINEERING, 2022

DESIGN BY PARKER HITT, BIOLOGY, 2024

To most, irrational numbers seem — well — irrational. We may be familiar with pi (π), Euler’s Number (e), and the square root of two, but a lesser known irrational number may hold many secrets to the universe: the Golden Ratio. From the Pyramids of Giza to the Mona Lisa to vegetables, this number can be found nearly everywhere.

The Golden Ratio occurs when a line is divided in two, where the longer part (a) divided by the shorter part (b) equals the total length of the line ($a+b$) divided by the longer part (a); a is to b as $a+b$ is to a . It is approximately 1:1.618 and is represented by the Greek letter Φ (Phi). Closely related is the Fibonacci Sequence, a series of numbers where every number is the sum of the two preceding numbers. For example: 1, 1, 2, 3, 5, 8, 13, 21 ... As the values become larger, the ratio becomes more accurate by accumulating more decimals.

This ratio can be found throughout nature. For instance, the spiral in sunflowers and pinecones follows the Golden Ratio. For both, seeds grow along two intersecting spirals that move in opposite directions, and every seed belongs to both spirals. In pinecones, eight seeds move in a clockwise direction, and thirteen move counterclockwise. In sunflowers, the numbers are even larger (21:34) and more accurate.

The iconic spiral can also be found in hurricanes, seashells, and even the human skull. A 2019 study from John Hopkins University compared 100 human skulls. The nasioniac arc connects the tip of the nasal bone to the inion, a small bump on the back of the skull, and the bregma is a curve on the top of the skull that follows a similar path that a headband would. In all of the 100 skulls researchers studied, they found that the bisection of these points creates two arcs whose distances exhibit the Golden Ratio.

Not only is the Golden Ratio embedded in our skulls, research has shown that it is hardwired into our brains. Adrian Bejan, professor of mechanical energy at Duke University, suggests that evolution has made the human eye capable of interpreting images featuring the Golden Ratio faster than those that do not.

Bejan argues that the human world is oriented horizontally rather than vertically. This is because attacks come from our

right, left, back, front, in between far more often than up or down. The scope of vision has evolved accordingly, and the eye takes in information more efficiently when it scans side-to-side. Over time, this field of vision has taken the proportions of the Golden Ratio. Our brain recognizes it and associates it with beauty and harmony without us even knowing.

For this reason, artists and designers take advantage of the aesthetic qualities of the proportion. The earliest known use dates back to 450 BCE, when Greek sculptor Phidias used it in his art. Since then, it has been used in paintings like Leonardo Da Vinci’s “Mona Lisa” and Salvador Dalí’s “The Sacrament of the Last Supper.” It has also been portrayed in buildings like the Parthenon in Athens, and renowned architect Le Corbusier relied on it for many of his projects.

Peter Wiederspahn, principal of Wiederspahn Architecture LLC and associate professor of architecture at Northeastern University, states that the Golden Ratio is steeped in Renaissance architecture and theory, with much of the inspiration coming from music:

“Not only is the Golden Ratio embedded in our skulls, research has shown that it is hardwired into our brains.”

“Sounds are based on intervals of chord progressions,” Wiederspahn said. “Sound is a natural phenomenon, but we can artificially create these phenomena.”

After years of experience in the field, Widerspahn has had an innate sense of the Golden Ratio since the beginning of his architecture practice. While it is applied “conscientiously or subconsciously,” the Golden Ratio makes sense in many designs. While some call it magical, others call it practical. It is derived from nature and unintelligent systems. Our mind’s eye is attracted to natural systems — for example, “a hospital window oriented towards a forest has more benefits to the human psyche than one that faces a parking lot,” said Widerspahn.

Whether we know it or not, the Golden Ratio is all around us, and we use it unknowingly on a daily basis. It raises the questions of why this ratio is so common and how the world, galaxy, and even universe are based on a divine proportion.

FIBONACCI'S FORMULA TO LIFE

A blueprint for beauty and nature

BY NETHRA IYER, CHEMICAL ENGINEERING, 2024

DESIGN AND PHOTO BY IAN PROULX, BIOENGINEERING, 2022

In the hit show “Criminal Minds,” Dr. Spencer Reid is known for his high intelligence and ability to see the world in a way that normal people cannot. One of his most iconic moments is in Season 4 Episode 8, where he is able to identify the link between abducted women and their location using the Fibonacci Sequence. He explains that it is “a ratio found all through life.” This is known as the Golden Ratio, best approximated by the Fibonacci Sequence, and is created geometrically through a logarithmic spiral. It is what society sees as beautiful, as some of the most enchanting and breathtaking aspects of nature follow this seemingly simple shape and sequence from flowers to sea shells.

“This goes to show that the simplest parts of nature, even those that can be found right outside any home, have a mathematical pattern necessary for life.”

The Fibonacci Sequence is named after Italian mathematician Leonardo Pisano, more commonly known as Fibonacci, who explained this series in his famous book, “Liber Abaci.” He poses the question: “*Quot paria coniculorum in uno anno ex uno pario germinentur?*” This roughly translates to “How many pairs of rabbits will spring in one year from one pair?” This assumes some parameters — like walls surrounding the rabbits, preventing them from escaping. Fibonacci then goes on to explain that the rabbit gives birth to one pair of rabbits and again during the second month. “*Quia suprascriptum par in primo mense germinat, duplicabis ipsum, erunt paria duo in uno mense.*” This means that because the pair of rabbits gives birth in the first month, there will be two pairs in the second month, and so on. The pattern then continues with each new pair also giving birth. Written numerically, it comes to 0, 1, 1, 2, 3, 5, and so on. To graph these numbers, squares are drawn, with sizes corresponding to each of the aforementioned numbers, with 1 being the smallest. In each square, a curve is drawn and connected to the previous, creating a spiral that can be seen all throughout the natural world.

One of the most common areas in nature where the Fibonacci Sequence can be seen is in flowers and pine cones. In many flowers, the arrangement or number of petals are actually Fibonacci numbers. For example, a lily found in a pond will have 3 petals, a wild rose will have 5 petals, and a daisy will have 55 petals. All of these numbers are in the

Fibonacci Sequence. According to the research article “The Fibonacci Sequence: Nature’s Little Secret” by Nikoletta Minarova, flowers follow this pattern because it “provides an evolutionary advantage in promoting the plant’s survival.” This means that the Fibonacci Sequence is like a code for survival for many flowers. This is due to the angle between each of the petals — the Fibonacci Sequence allows for flowers to have specific angles that are best for growth.

Flowers are not the only aspects of nature where the sequence can be seen. Many pine cones also follow the spiral created by those numbers. Each fold in the pinecone is a spiral. The first moves from top to bottom, whilst the second moves from bottom to top. Minarova gives an example of how one pine cone has a spiral that reaches the number eight, followed by a spiral that reaches the number 13 in the opposite direction, and so on. This goes to show that the simplest parts of nature, even those that can be found right outside any home, have a mathematical pattern necessary for life.

The Fibonacci spirals are also found near the sea, with seashells being some of the most studied. The most famous seashell is the nautilus shell, which has chambers that follow the shape of the logarithmic spiral. The nautilus shell is known for having the “golden proportion,” both because of its color and the fact that it is perfectly proportioned with the Golden Ratio, which is approximately 1.618. The Golden Ratio, or Phi, comes from dividing one number of Fibonacci’s sequence by the one preceding or succeeding it. Mathematicians and scientists are still unsure as to how the nautilus shell is and has been so perfectly proportioned for millions of years.

From flowers to pine cones to seashells, the Fibonacci Sequence not only makes them visually appealing but also helps in their survival, even since the age of dinosaurs. It is interesting to note that in a universe so filled with disorder, one is always trying to reach a state of entropy with some of the most curious and beautiful things being due to a simple mathematical sequence.



A sight to behold

Supernovae through the eyes of an artificial intelligence

BY ANNABELLE MATHERS, CIVIL ENGINEERING, 2022

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Only 0.1 percent. Without artificial intelligence (AI), cutting-edge astral observatories around the world may be able to comprehensively classify only 0.1 percent of the approximately 1 million supernovae observed yearly. Ashley Villar of Columbia University, along with many other experts, is aware of the limitations of data collection using human techniques. In response, these experts have developed an artificial intelligence program that conducts data analysis rapidly and accurately enough to make traditional techniques for observing supernovae increasingly irrelevant. The sheer amount of potential discoveries made possible by the pattern-based conclusions of a nuanced and efficient AI is overwhelming, but it is a clear step forward in understanding the magnificent explosions of deep space.

Essentially, supernovae occur when a white dwarf or massive star experiences extreme physical events that often result in its explosive transformation into a neutron star or black hole, respectively. White dwarfs lacking nuclear fuel may accumulate mass from nearby stellar objects or mergers, which causes core instability, nuclear fusion, and an eventual explosion. Conversely, massive stars lacking nuclear fuel may absorb surface mass into their core, causing gravitational instability, collapse, and an explosion. The light produced by these explosions can appear over 100 times more luminous than the initial solar luminosity.

Optical spectroscopy is the traditional method of supernova classification, where the appearance of certain light waves (recorded and observed on a color spectrum) indicates the presence of certain elements associated with the exploding star. Unfortunately, spectroscopy is a slow and resource-intensive process, making it virtually impossible to observe and record the colorful spectra from every single supernova. A quicker classification method uses photometric light curves emitted by supernovae; however, this method is far more difficult for humans than for AI programs trained to recognize explosion patterns. Characteristics of a star, and phenomenological behavior of its supernova, correlate with certain spectra and certain light curves. By observing these curves, particularly the evolution of the visible brightness of a supernova, AI can categorize supernovae similar to the categorization provided by spectroscopy.

Furthermore, this relationship between spectra and light curves is important for developing the AI program itself. The Pan-STARRS1 Medium Deep Survey (PS1-MDS), conducted

with a telescope based at the University of Hawaii, contains data from over 5,000 supernovae events — its sheer breadth is crucial to developing a more accurate AI. With this unprecedented study, experts recorded traditional spectra for over 500 supernovae, which were then used to train the AI. Once the AI recognized correlations between spectra and classifications of these recorded supernovae, the AI learned to associate the light curves of those same supernovae with the spectra-based classifications and characteristics. As a result, the AI can now classify supernovae only using light curves. It is the large set of observations of real spectra from these real supernovae that acts as a revolutionary cheat sheet to initiate the machine learning process. Typically, the lack of spectra data prompts experts to train AI with synthetic data, which often results in AI that cannot properly account for the unpredictability and nuance of real supernovae.

Thus, the use of empirical data to train the AI provides more accurate classification of supernovae as shown by the Python-based SuperRAENN and the subsequently inspired Superphot. Villar et al. developed SuperRAENN (recurrent autoencoder neural network) through semi-supervised data training, the concept which Griffen Hosseinzadeh et al. reconstituted into Superphot using a refined classification methodology. Superphot used light curves to quickly classify 2,315 supernovae with an 82 percent rate of accuracy, a stark contrast to the previous painstaking spectroscopy. However, the process is imperfect, and some similar classifications are frequently misassigned because of the extremely nuanced nature of the light curves and explosive phenomena.

Noting these imperfections, experts continue to develop these AI programs and even allow public access to study results, data, and code. As astronomers collect more data, particularly through the online integration of observatories like Chile's Vera C. Rubin Observatory, the training of AI may become increasingly comprehensive and accurate. By enhancing the scientific community's current understanding of both anomalies and holistic trends in supernovae, AI also contributes to the understanding of other cosmic phenomena like black holes and the intergalactic dispersion of elements. It remains to be seen what other mysterious aspects of space and supernovae can be illuminated when artificial intelligence turns its eye to the night sky.

The Astrophysical Journal (2020). DOI: 10.3847/1538-4357/abc6fd
The Astrophysical Journal (2020). DOI: 10.3847/1538-4357/abc42b

TERRAFORMING MARS

The hard science & bizarre culture surrounding the sci-fi concept

BY NOAH HAGGERTY, APPLIED PHYSICS, 2024

DESIGN BY KAI GRAVEL-PUCILLO, ENVIRONMENTAL SCIENCE, 2022

Elon Musk walks out to applause for his September 2015 interview on “The Late Show with Stephen Colbert.” After exchanging pleasantries, Colbert asks Musk about his fascination with our closest solar neighbor: “You sincerely think that we should go to Mars ... Why do we want to go to Mars? It’s uninhabitable.”

“It is a fixer-upper of a planet,” Musk responds, eliciting laughter from the audience. “At first you’re going to have to live in transparent domes, but eventually you can transform Mars into an Earth-like planet.”

The concept Musk is referring to — transforming the environment of another planet to make it hospitable for human life — is known as “terraforming” and was first coined by science fiction writer Jack Williamson in 1942. Terraforming Mars would require raising its atmospheric pressure from 0.006 atmospheres to Earth’s 1 atmosphere and increasing the temperature by about 60 degrees Celsius. Many methods for achieving this have been proposed, some as implausible as multi-kilometer wide space mirrors to reflect extra sunlight onto the planet and bioengineered extra-tough Martian plants to develop the atmosphere. The most discussed and scientifically realistic proposal involves extracting carbon from the surface and releasing it into the atmosphere to create a greenhouse effect (the same mechanism driving climate change on Earth). The concept has steadily grown in popularity, exploding in recent years. It has gained an almost cult-like following, assisted by Musk and other advocates for a human mission to Mars — including aerospace engineer and author Robert Zubrin and director Chris McKay, best known for “The LEGO Batman Movie.”

Colbert presses Musk. “How would you warm Mars up? You know it’s a long way away from the Sun.”

Musk chuckles. “The fast way is [to] drop thermonuclear weapons over the poles.”

“You’re a supervillain!” Colbert retorts, poking at the absurdity of the statement. Nevertheless, the concept has been seriously considered by scientists and put through the rigor of the scientific process. So, could it work?

“No, it will not work,” says Dr. Bruce Jakosky, a planetary scientist and the principal investigator for NASA’s MAVEN Mars Orbiter, focused on studying the Martian Atmosphere. “Nuking the poles would release any CO₂ that is trapped there back into the atmosphere ... This would ... not produce any significant greenhouse warming,” Jakosky told *Nu Sci*. He authored a 2018 paper taking inventory of all the accessible carbon reservoirs on Mars that could be used in a terraforming process. The

list is exhaustive, including carbon that has been absorbed by Mars’s iconic red surface material, carbon molecules buried deep in rich mineral plains, and carbon frozen in the polar ice. However, releasing all this carbon would be a virtually impossible task, likely requiring future Martians to strip-mine and scorch practically the entire surface and detonate explosives or nuclear weapons at the poles, yet all of this would only increase the pressure to, at most, roughly 20 percent of Earth’s.

When asked if he believed there was consensus within the scientific community supporting his conclusion, Jakosky said, “Yes, but consensus does not imply unanimity,” joking, “I suspect that Chris McKay might disagree with my conclusions,” referring to the pro-terraforming “LEGO Batman” director. While scientists agree that terraformation will not be possible without a paradigm shift in humanity’s technological capability, which NASA publicly agreed with in a 2018 press statement, there is a large portion of space and science enthusiasts who reject this consensus.

These individuals find community in the Facebook group for Zubrin’s space exploration advocacy organization “The Mars Society.” Members frequently share terraforming artwork, affirming articles, and their own terraformation ideas — sometimes done so in personal PDF files masquerading as scientific papers. These eccentric ideas range from deliberately smashing asteroids into Mars to funneling particles from space into the atmosphere using a colossal orbiting magnetic ring the size of New York City. Users post and ridicule the 2018 NASA press release regularly — almost three years after its publication.

Terraformation is, at its heart, a product of science fiction and not a rigorous scientific concept, and there is a real risk in conflating a science-fiction thought experiment with reality. Jakosky warned, “I think it’s dangerous to take seriously the idea that Mars can serve as a ‘backup’ planet in case the Earth becomes uninhabitable. If we believe that, it’s too easy to fall into the trap of not taking care of the Earth ... It’ll always be easier to fix our climate than to change the Martian climate into one that is suitable for us.”



Opinion:

Stargazing will be redefined for future generations

BY SHARMILA KUTHUNUR, JOURNALISM, 2022

My generation may be the last to be able to gaze upon a star-studded sky.

One night in early 2017, from the terrace of a relative's home in a tiny village in India, I was astonished and delighted to see the sky packed with stars. Many glowed dimly but steadily. A handful of them had to be planets in our system. Countless of them were untouched worlds far away.

Four years later, I still remember that feeling of wonder and yearning to share that with the next generation. While they will see the night sky dotted with lights, I fear those dots will consist more of satellites than of stars. The few stars that will be visible may be indistinguishable from the swarm of satellites that will be orbiting above the Earth.

Since May 2019, SpaceX has been steadily deploying satellites into low-Earth orbit to build a satellite constellation. It placed 60 satellites in orbit on February 5, according to tweets from the company. Missions will continue, culminating in 42,000 satellites in orbit.

SpaceX plans to provide a high-speed internet connection to every corner of earth through Starlink. Musk told reporters in 2019 that Starlink is "a way for SpaceX to generate revenue" to "develop more advanced rockets and spaceships."

"We think this is a key stepping stone on the way to establishing a self-sustaining city on Mars and a base on the moon," said Elon Musk in 2019.

The first step to going to the moon and Mars is to have a clear orbit to launch spacecraft. It seems contradictory that Musk is crowding the orbit with satellites while using that money to try and get through the same interface.

In September 2020, Washington state's first responders tweeted appreciation and used Starlink internet to connect with residents after a fire destroyed parts of the town of Malden. But positive instances of an expensive internet connection are few and far between.

The satellites, which are already 99 percent brighter than other satellites in space, change orbits autonomously. For astronomers, "observations cannot be scheduled to avoid them," according to a prepublished paper outlining concerns astronomers face.

SpaceX satellites are arranged in a line, just 200 miles above Earth, where they leave trails of reflected light in their wake. According to the paper, the satellites are bright enough to be seen with the naked eye, especially before sunrise and after sunset — when most observations in astronomy occur. The satellites reflect sunlight, thereby blinding sensitive telescopes from seeing past their scintillating barrier. Even if only a handful of them pass through a telescope's view, they mar observations.

More than 2,000 astronomers on a blog are formally appealing to institutions and governments to intervene so that they can be guaranteed "the right to observe a sky free from unnecessary artificial polluting sources."

The backlash led SpaceX to darken the satellites. But they couldn't darken the solar panels (which made up 75 percent of the brightness) and keep the satellites running at the same time, making the entire effort nearly useless. So, satellites are now "photobombing" astronomy images.

Soon, these satellites will redefine astronomy. Gone will be the Big Dipper, Orion, and other constellations. Those familiar patterns will be replaced by artificial satellite constellations. I

DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

fear that one day my kids might say, "Look, Mommy! I see the Starlink Constellation!"

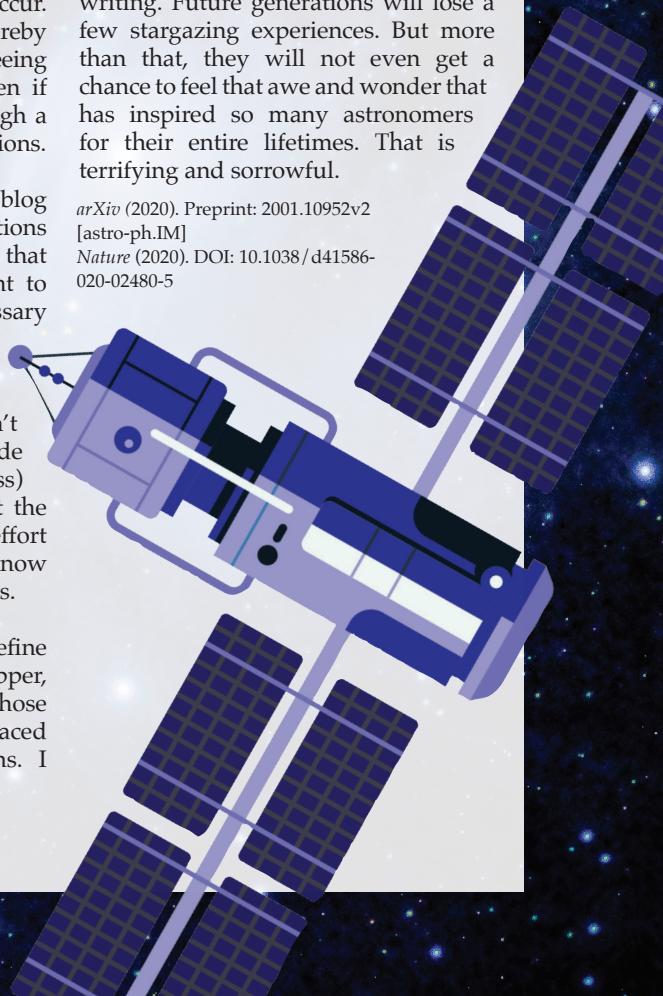
In an article for *Scientific American*, research astronomer Ronald Drimmel mourns the loss of not just stars from view, but also the significance of a star-filled sky. For generations, it has reminded every person who has looked up "that we and our problems are small, and that our meaningfulness may finally lie just in our ability to recognize and admire the wonder and beauty of a universe larger than us, yet of which we are a part."

We are very close to losing that dome and our sense of connectedness along with it. The night sky I'd looked up at on that night in 2017 continues to fuel me with wonder. It has influenced my interest in astronomy and in science writing. Future generations will lose a few stargazing experiences. But more than that, they will not even get a chance to feel that awe and wonder that has inspired so many astronomers for their entire lifetimes. That is terrifying and sorrowful.

arXiv (2020). Preprint: 2001.10952v2

[astro-ph.IM]

Nature (2020). DOI: 10.1038/d41586-020-02480-5



LOVE, ACTUALLY

The neurochemistry of falling in love

BY KAELEN ENCARNACION, BIOLOGY & ENGLISH, 2021

DESIGN BY RACHEL LINES, BEHAVIORAL NEUROSCIENCE, 2023

Love holds many definitions. In the Google Dictionary, it's described as "an intense feeling of deep affection," and similar, often more complex definitions can be found in philosophy, poetry, art, literature, and film. It means different things to different people and refers to not only romantic attachments but also familial, platonic, or sexual connections. While we may typically associate these warm feelings with our heart, it's commonly understood that the scientific basis of love is actually just hormones and chemicals passing through our brains. Not as romantic, huh?

On the molecular level, the different kinds of love can be distinguished depending on the chemicals released. These variations are thanks to the hypothalamus, the region of the brain that is largely involved in controlling hormone release from the pituitary gland. With lust and sexual attraction, the sex hormones testosterone and estrogen come into play, increasing libido in both men and women. With romantic attraction, or when a person first starts dating or "falling in love" with someone, phenylethylamine, norepinephrine, and dopamine play important roles. Phenylethylamine (PEA) can be found in chocolate, a debated aphrodisiac, and acts as a stimulant, which leads to the release of norepinephrine and dopamine. It has been observed that people who report to be "in love" have higher levels of PEA in their brains than those who do not. Norepinephrine, more commonly associated with the fight-or-flight response, leads to increased heart rate and sweaty palms, as well as the giddy, energetic feeling that can

explain why one may not be able to eat or sleep normally when they are in love. Furthermore, dopamine, also known as the "reward hormone," is released when the body feels pleasure, creating the euphoric "head-over-heels" feeling.

With deep romantic attachment, such as commitment and long-term relationships, oxytocin and serotonin are also heavily involved. Oxytocin, or the "love hormone," is stimulated by physical touch and has been observed to strengthen social trust

and professor Dr. Stephanie Cacioppo demonstrated that both love and lust lead to increased activity in the "subcortical brain areas associated with euphoria, reward, and motivation, as well as in the cortical brain areas that are involved in self-representation and social cognition." With lust however, activity is reduced in the ventral striatum, amygdala, hypothalamus, inferior parietal lobule, and somatosensory cortex. This suggests that sexual desire is driven by a specific physical goal, whereas love is driven by more abstract and behaviorally complex goals. Meanwhile, love is associated with greater activity in dopamine-rich areas of the brain involved in reward, motivation, and habit formation, which makes sense considering love is often seen as a rewarding, positive, and motivating experience.

“Love does indeed seem to have a ‘formula,’ even if the poets disagree.”

in mammals. It is typically secreted during moments of intimacy, such as breastfeeding, childbirth, hugging, holding hands, and sex. Serotonin, or the "happiness chemical," is involved in regulating appetite and mood, but it also participates in the brain's reward system. Adversely, serotonin is often associated with addiction, and abnormal levels of this hormone can lead to over-dependence or even obsession in relationships.

In neuroscience, love and lust can activate similar areas of the brain. A 2012 fMRI study led by neuroscientist

Considering the scientific evidence, love does indeed seem to have a "formula," even if the poets disagree. But, while these chemicals can be synthesized in a lab, love cannot simply be reduced to an emotional drug addiction. Equally as important in falling in love is simply the intention to be with a significant other. In other words, love is ultimately a choice. It may have multiple definitions — philosophically, poetically, scientifically — but everyone has the ability to find their own meaning of love.

The Journal of Sexual Medicine (2010).
DOI: 10.1111/j.1743-6109.2010.01999.x

PHOTOS BY SHUTTERSTOCK



A brief history of memes:

The forgotten past of an internet phenomenon

BY BEN WEINTRAUB, COMPUTER SCIENCE PhD, 2024

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

In February 2015, the internet was afire with debate about a dress. #TheDress, as it became known, was a picture of a dress that people either saw as black and blue or gold and white. A matter of chromatic perspective, and certainly a problem with no right answer, #TheDress was the subject of heated debate for days.

It turns out that this phenomenon is the natural result of an important concept in evolutionary biology. Richard Dawkins introduced this concept in his 1976 book, *The Selfish Gene*. His main thesis was that it is more productive to consider the gene as the unit of replication rather than the organism. And in fact, Dawkins argues, the gene itself is not unique in being a *replicator*. A replicator is any entity that undergoes three specific processes: replication, variation, and selection. Dawkins goes on to say that many such replicators can exist in nature and that we should not restrict our thinking to include only the DNA-based kind.

One such replicator is the *meme*. The word “meme” was coined by Dawkins himself in the same book. It is a word designed with etymological intention. Stemming from the Greek *mimene* — meaning imitation — and shortened to a single syllable, the word itself is an ode to its conceptual forebear, the gene. While a gene spreads itself through gametes, like sperm or eggs, in the gene pool, “memes propagate themselves in the meme pool by leaping from brain to brain” in a process that could be described as imitation. Every leap to another brain is an instance of replication, and just like the children’s game telephone, bits of information may be lost or morphed with each transmission. The memes that appeal to their hosts’ sensitivities are more likely to be propagated to another brain, so as a weak meme replicates and loses its appeal, its ability to spread diminishes too.

Memetics researcher Dr. Susan Blackmore put it more casually, saying, “[m]emes are stories, songs, habits, skills,

inventions and ways of doing things that we copy from person to person by imitation.” In a more formal sense, memes are information — the same as genes. The only difference is that they are stored on a different physical medium: DNA for genes and neural networks for memes.

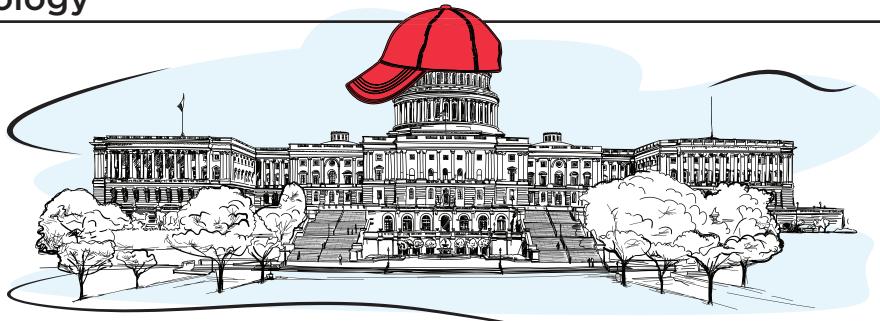
Every leap to another brain is an instance of replication, and just like the children’s game telephone, bits of information may be lost or morphed with each transmission.”

Some scientists, however, go so far as to say that memes can be described as *de facto* living structures. They claim that a meme is literally a neurological symbiote, using the brain to propagate itself. Juan Delius, professor emeritus of psychology at the University of Konstanz in Germany, said of the matter, “any cultural trait taken over by a given individual from another individual must accordingly be thought of as the transfer of a particular [neural] pattern [...] of one brain to another.”

From this perspective, memes, such as #TheDress, become less a cultural phenomenon and more an instance of the predictable forces of evolutionary theory. Viewed as such, the spread of memes can be studied and modeled like viruses in the gene pool. It’s no coincidence that a popular meme is termed “viral.”

In classical evolutionary theory we would have to confront the question: In what way is #TheDress advantageous to the host, thus enabling it to spread? This turns out to be an irrelevant question, however, because in selfish gene theory, a meme (or gene) need not be advantageous to its host. It may spread because, in Dawkins’s words, it is “advantageous to itself.” A virus spreads because it hijacks its host’s cell-manufacturing machinery; likewise, a meme spreads because it hijacks its host’s decision-making ability. In other words, the memes that spread on the internet are the ones that trigger some form of action. The real question we must ask ourselves then becomes a different one: Are we in control of spreading memes or do they control themselves?

Scientific American (2000). DOI: 10.1038/scientificamerican1000-64



Opinion:

A profile of the alt-right and modern American conservatism

BY BINH DANG, ENGLISH, 2022

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

A deadly rally in Charlottesville, a slew of mass shootings, a divisive general election, and an insurrection based on unfounded claims of voter fraud. The United States is more openly divided than it has been since the Civil War, and the extremist right wing of the country has become emboldened over the years. During the Charlottesville “Unite the Right” rally in 2017, America saw an outing of neo-Nazis, Confederate sympathizers, and Ku Klux Klan members chanting racist and bigoted epithets. Among the sea of Nazi and Confederate flags was another symbol of support: merchandise touting “Make America Great Again.”

While then-President Donald Trump condemned these groups, he still infamously said there were “very fine people on both sides.” Among those who Trump was trying to appease were right-wing hate groups like the Proud Boys who openly supported the former president, yet over 74 million Americans voted for him in 2020. Because of this, it’s worth taking a look at the psychology of the alt-right to understand their motives and why this association didn’t deter nearly half of all voters from supporting the incumbent Republican.

Despite what the name suggests, the “alt-right” isn’t a fringe, alternative right-wing ideology with a small following. It’s estimated that 3 percent of the general U.S. population, or over 3 million people, identify their support for the alt-right. The group is associated with paleoconservatism, antiestablishmentarianism, anti-Semitism, racism, White nationalism, anti-immigration — essentially any flavor of White supremacy and reactionary politics that upholds the oppressive power structures that harm marginalized groups.

That last addendum isn’t an uncharitable characterization of the movement; a 2019 study in *Perspectives on Psychological Science* showed alt-right Trump supporters scored highest in social dominance orientation (SDO), a personality trait measuring an individual’s support for social hierarchies and ingroup dominance. In comparison, those who identified as non-alt-right Trump supporters scored only slightly lower in SDO, and (non-alt-right) non-Trump supporters scored the lowest. In addition, both Trump-supporter groups scored higher than non-Trump supporters in ideologically neutral authoritarianism, a metric measuring rigid adherence to and enforcement of social norms and traditionalism.

Essentially, those who score higher in SDO typically believe that the world is inherently unequal and ruthless — a dog-eat-dog world. To secure safety, one must form coalitions based on ingroups and outgroups. The alt-right’s ingroup of choice

is predominately White males, indicated by the fact that they expressed more concerns about discrimination toward White people and men. Their outgroups coalesced around their choice to exclude non-White people, this division being reflected in their higher scores in the “blatant dehumanization of derogated and opposition groups,” “motivation to express bias toward Black people,” and “desire for collective action on behalf of Whites.” That hierarchical domination is even more concerning when authoritarianism comes into play. Those scoring high in that metric are more willing to submit to perceived legitimate authority, follow societal conventions, and punish those who deviate from those norms. The alt-right sees Trump as a legitimate authority and the institutions that he attacks — such as mainstream media — as illegitimate authorities that deviate from ingroup norms. Interestingly, despite their popular anti-establishment reputation, the alt-right supports Trump significantly more than non-alt-rightists.

II Essentially, those who score higher in SDO typically believe that the world is inherently unequal and ruthless — a dog-eat-dog world.”

The researchers only found a few differences between alt-rightists and non-alt-right Trump voters when compared to non-Trump supporters. The alt-right were more likely than their non-alt-right counterparts to trust alternative media, express value-based bias towards Black people, and desire collective action on behalf of White people.

The alt-right’s motivations center around White social status. Other studies have also pointed to the threatened-status narrative to explain the alt-right’s spread in the United States. Although White people have been and will continue to be the majority power holders in the country, increases in representation and power of minority groups will close that gap. Because of this trend, it seems unlikely that the alt-right will let their influence in American politics diminish. More concerning is that while not every conservative is an alt-rightist, they share much more in common with them than should be comfortable, and social media’s affinity for political polarization may facilitate this ideology’s spread even more.

I don’t doubt that this article’s subject matter is contentious. Most people across the political spectrum simply want to live decently without the aggression that extremists engender. However, it’s important, now more than ever, to take a critical, empirical look beyond party affiliation at the movements coming to power and their intentions so that we can achieve a good and dignified future for all.

HERE COMES THE SUN:

How sunflowers tilt toward the light

BY CERINA CARR, BIOLOGY, 2023

DESIGN BY PARKER HITT, BIOLOGY, 2024

Helianthus annuus, commonly known as sunflowers, were named for their tendency to turn towards the sun throughout the day, almost as if they're sentient. This phenomenon, known as heliotropism, is not unique to sunflowers; most species of legumes also turn towards the sun. However, since the head of the sunflower is so prominent that you can always tell which way it is facing, it is a common subject in studies of heliotropism. Predictably, plants face the sun to optimize light capture — but how do plants "know" where the sun is?

In many heliotropic plants, including the sunflower, the turning is caused by a structure called the pulvinus, located at the point where the leaf connects to the stem. The pulvinus can become more or less rigid based on the pressure of water on the cell walls, also known as turgor pressure. As this change in pressure alters the rigidity of the pulvinus, the whole leaf moves.

This solar tracking behavior may seem simple at first glance; plants benefit from light from the sun, so they face towards it. However, there is still a lot of missing information regarding this phenomenon. At night, sunflowers have been observed to reorient themselves eastward in anticipation of the sunrise. If sunflowers simply direct themselves toward the sun, then how do they know which way to face at night? Also, how does the direction of sunlight indicate the change in turgor pressure that causes the leaves to turn?

What have we learned from experiments?

An experiment from the 1890s sought to uncover which part of the sunflower is responsible for its heliotropic behavior. It was discovered that cutting off the flowering head did not prevent solar tracking, but removing the leaf blades stopped this behavior entirely. A review paper by Vandenbrink et al. remarked that "these results do not distinguish whether the mature leaves function as the location of light reception, the source of a diffusible signal, and/or the source of energy to support the movement." This experiment was one of the earliest recorded experiments on sunflowers and led to many more studies focused on uncovering the mechanisms behind heliotropism.

Sunflowers have a circadian rhythm, just as humans do. In one study, sunflowers were turned 180 degrees at night to see if they would adjust to the new pattern of sun movement. The sunflowers maintained their original

movement patterns for several days before they adapted to their new positions and reoriented to once again track the sun. This showed that following the sun during the day is a trained behavior, and that sunflowers become accustomed to a certain cycle. Just like human sleep cycles, it can take days (or weeks) to adjust to a new one.

The mechanisms by which plants alter water uptake within the pulvinus are not fully understood. One study found that increased sunlight on one side of a plant led to



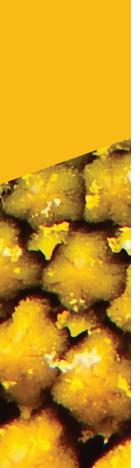
Plants may seem like simple, immobile organisms, but in reality they move as though there is conscious planning involved."

increased acidity in the surrounding tissue. This acidity led to more flexibility in the cell walls of the illuminated side, which coincided with stem bending. There have also been molecules identified to be involved in solar tracking. Auxin, a type of plant hormone, has been found in different concentrations between the illuminated and shaded sides of a plant and correlated with different growth rates in each side. Another type of plant hormone, gibberellin, has also been found in different quantities between the illuminated and shaded parts.

Research on sunflowers has come a long way since 1890. Much remains to be discovered, and sunflowers are just one of many plants that exhibit heliotropism. Plants may seem like simple, immobile organisms, but in reality they move as though there is conscious planning involved. Clearly, plants are more complex and intelligent than we give them credit for.

International Journal of Plant Sciences (1898). DOI: 10.1086/327699
Plant Science (2014). DOI: 10.1016/j.plantsci.2014.04.006
Journal of Photochemistry and Photobiology (2002). DOI: 10.1016/S1011-1344(02)00234-8

PHOTO BY FDECOMITE



Tree Sexism Why – Achoo! – allergies get so bad

BY ASHLEY BROWN, BIOCHEMISTRY, 2024

DESIGN BY KATIE GREEN, BIONENGINEERING, 2022

As spring approaches, albeit slowly, the threat of allergies encroaches. Seasonal allergies, often due to pollen, leave the afflicted congested, with itchy eyes and more. These symptoms all stem from a common denominator: pollen, or in other words, plant sperm. The immune system is primed to maintain balance in the body by removing potential threats, either through specific means such as antibodies or nonspecific means like mucus. This overzealousness can result in more regular environmental factors such as pollen initiating an immune response that causes the aforementioned symptoms. The sheer scale of this response, though, is an artificial creation, one grown from tree sexism.

Firstly, it is important to review the reproductive systems in most deciduous trees to understand how this issue arises. Trees are able to reproduce asexually through male and female flowers on the same tree or sexually through pollen exchange between different trees. While there are multiple methods to facilitate this pollen exchange, such as birds and butterflies, wind pollination is the mode primarily responsible for pollen spreading in the greater environment and, as a consequence, into humans. Once the pollen from a male tree reaches a tree with female organs, the tree is fertilized and creates a seed. Ultimately, these seeds can result in fruit, nuts, or new trees entirely.

This is where the issues with urban planning begin. As reported in *Scientific American* by Thomas Leo Ogren, a prominent horticultural epidemiologist, the 1949 Yearbook of Agriculture released by the United States Department of Agriculture (USDA) advises that “[w]hen used for street plantings, only male trees should be selected, to avoid the nuisance from the seed.” Ogren describes how this did not immediately compound on allergies in urban populations until the American Elm, the traditional street tree of cities, fell prey to a wave of Dutch elm disease, severely damaging the population. To replace them, the USDA’s advice was followed, and male trees, devoid

of female flowers either naturally or through selective breeding, were planted around cities.

From this point on, a distinct spike of allergies and asthma grew in cities. This spike is related to how the immune system and pollen interact. In a review of the relationship between the human body’s response to allergies and asthma, Dutch immunologist Gert-Jan Braunstahl, MD PhD, describes the immunological response in detail. Both the symptoms of asthma and allergies stem from the body’s inflammatory response. The immune system identifies the excess pollen as a threat, and this activates inflammation, a nonspecific response, from the nasal passage down the throat to the bronchial tubes. Without this additional pollen in the environment, these responses would not be so drastic, as it would not antagonize the immune system to the degree it currently does.

Ogren offers a solution to the issue of pollen in cities: returning female trees to the city. These trees will absorb the excess pollen, and they would be allowed to form fruit. While Ogren also adds that these trees would also absorb pollutants such as those from cars and result in poisonous fruit, it is simpler to teach others to not eat the fruit rather than “not to inhale pollen from the air around them.” This active allergy-fighting potential would more than justify the time spent on education for how to treat the return of fruit to city life. Without this addition, rates of allergies and asthma will likely only continue to increase to the determinant of those living in cities.

Until this change can occur and become widespread among cities though, you can remember this spring that when your allergies act up, it is okay to blame the patriarchy.

Journal of Allergy and Clinical Immunology
(2004). DOI: 10.1016/j.jaci.2004.10.041

PHOTOS BY SHUTTERSTOCK



Materials that mimic the lotus effect

Lotus leaves inspire self-cleaning surfaces

BY JESSICA HEALEY, MECHANICAL ENGINEERING, 2024

DESIGN BY KATIE GREEN, BIONENGINEERING, 2022

The study of preexisting designs is a common practice for guidance in problem solving. Innovators can turn to structures around them for inspiration, and what's a more complex and functioning system than nature? In terms of hydrophobic properties, or water-repellant behavior, scientists strive to mimic the lotus effect. This effect is named after the leaves of lotus plants, which demonstrate a self-cleaning nature, as microscopic structures ensure that water, dirt, bacteria, and other materials simply roll off the surface. Scientists have examined this plant's biological and chemical compositions, providing constructive insight into waterproofing materials and advancing technology in a uniquely natural way.

The structure and chemical composition of lotus has a greater stability and water repellency compared to other plants, thus making it an efficient model to study. The lotus leaf's rough shape and wax tubules generate a surface that resists water; this rough exterior is covered with uneven bumps called papillae. These papillae induce water droplets into spheres to reduce the droplets' surface energy, a measure of the energy present at the surface of a material due to the disruption of intermolecular bonds. Molecules want to have low surface energy, so molecules at the surface of a solid will attempt to create new bonds to become more stable and exist in a lower-energy state. The formation of a sphere is the geometric way to minimize the water's surface energy. In another process called wetting, two surfaces touch to create agreeable, lower-energy interactions through adhesion, minimizing the solid's surface energy. When a water droplet lies on a lotus leaf, stretching to fill the spaces in the uneven surface would increase the water droplet's surface area and thus surface energy. Therefore, wetting is inhibited, and geometrical optimizations occur to reduce surface energy. The lotus' microscopic bumps cause the contact angle to surpass 150 degrees, prompting the droplets to roll right off the leaf. For reference, the contact angle of a water droplet on a hydrophilic surface is less than 30 degrees, and a hydrophobic surface's contact angle with water starts at 90 degrees and increases from there. Additionally, the leaf's wax tubules consist of nonpolar methyl groups, further rejecting adhesion with water because of water's polar nature.

Wilhelm Barthlott, a German botanist and materials scientist, struggled to create hydrophobic material that would repel external substances while adhering to the object being protected. After discovering the lotus effect, he created the "honey spoon" — a product with an irregular silicone surface that caused honey to roll off it. This product sparked an interest from large companies who started to research applications for

the technique. Applications of waterproofed materials range from the prevention of residual graffiti on facades to coating valuable objects such as cell phones. Waterproofed materials have an extended life and an improved appearance, proving advantageous in many ways. For example, the lotus effect promotes visibility when applied to glass and windshields. A hydrophobic layer on the glass can decrease glass corrosion, hinder dirt's ability to stick, and reduce cleaning expenses. Sto Corporation's Lotusan paint is a self-cleaning coat of paint that mimics the lotus leaf microstructure as well. Like most products that mimic the effect, the ridges that rise and fall on the surface minimize water and dirt's contact area. It protects buildings' surfaces against wear and tear, weather, and mold. Furthermore, microorganisms have a reduced chance of sticking to the surface; germs are less likely to

“Scientists have examined this plant's biological and chemical compositions, providing constructive insight into waterproofing materials and advancing technology in a uniquely natural way.”

survive on a surface coated in Lotusan. Nanotechnology, which includes robots, textiles, and much more, is another area that has replicated the self-cleaning properties of the lotus plant. A rough nanoscopic surface can be etched onto the exterior of materials to maximize water repellency. Water repellent nanofabrics can consist of nanofibers or regular fabric coated in a solution of nanoparticles. In clothing or interior textiles, water- and stain-resistant properties are vastly beneficial. Fiber Secret's Lotushirt contains nanofabric designed to mimic the meticulous, uneven structures of the lotus leaf. The outside of the shirt is able to hold off stains and water, leaving customers satisfied with its lightness and durability.

In addition to the extensive application of the lotus effect to establish water-resistant surfaces, the hydrophobic properties of the plant accentuate its own beauty. From murky, muddy environments, its vibrant petals and sturdy leaves rise. As the lotus plant sows the seed of scientific innovation, its bloom serves as a reminder to let the dirt roll off our backs and prevail through adverse conditions.

Beilstein J Nanotechnol (2011). DOI: 10.3762/bjnano.2.19
PHOTO BY SHUTTERSTOCK



How plants help reduce stress

BY EMMA TUSUZIAN, PSYCHOLOGY, 2023

DESIGN BY CARINA HALCOMB, EXPERIENCE DESIGN, 2024

As more time is spent inside, creating an environment of comfort and productivity indoors has become a significant hurdle. The extra stressors of lifestyle changes and online work are some of the new barriers for staying motivated. Optimizing workspaces within the home has become especially important, as even small changes can reduce the stress and anxiety that may be exacerbated by an unfriendly environment. In searching for ways to breathe a bit easier within the home or workplace, researchers have identified one particular element that can produce both physiological and psychological improvements: plants.

Houseplants have long been symbols of the idyllic work area, often seen plastered on home improvement magazines and social media profiles. However, their visual benefits are only a small part of what makes plants welcome roommates. According to a 2015 study about indoor plants published in the *Journal of Physiological Anthropology* by Lee et al., indoor plants have been shown to improve job satisfaction, mood, and cognitive health, helping resist chronic stress and reducing the potential to exacerbate diseases.

Plants truly show their worth during moments of stress. Multiple studies have indicated an ease in both physical and mental stress due to the presence of an indoor plant. A 2019 study in Japan investigated changes in these two manifestations of stress before and after placing a plant on workers' desks. Sixty-three office workers were directed to take a three-minute rest while sitting at their desks when they felt fatigued. Participants were able to see and care for a small plant of their choice and were compared to participants who sat without plants. When considering the different interactions with plants and their effect on mitigating stress in the workplace, researchers saw that intentionally gazing at the plant was an interaction office workers could "do quickly and easily at their desks." The study calculated a significant decrease in anxiety post-intervention. Researchers suggested having plants within sight contributed to overall reduced stress, speaking to the potential mental health benefits of these unique green colleagues in moments of high pressure or fatigue.

With the growing fatigue brought about by technology and overstimulation, interacting with indoor plants has been seen to produce a soothing effect on the senses. Research has shown plants can suppress the sympathetic nervous system and blood pressure while promoting feelings of comfort.

This has become increasingly significant as researchers study the effectiveness of a natural environment on subduing the stress of technology usage. Interacting with a plant, such as transplanting or tending to it, lowers these physiological measures of stress and provides a needed break from the mental involvement of a computer task. With constant internet usage becoming even more prominent for many across the country during the pandemic, the extra strain and discomfort from computer work are a part of daily life across the United States. As such, a source of comfort and relaxation is incredibly necessary for ensuring balance within a lifestyle that can become blurred by days of online work. Keeping an indoor plant is one way to inspire breaks, even just by taking moments to tend to it.

In addition to their stress-reduction benefits, plants may aid in surgery recovery simply by being in the room. A study on patients recovering from a hemorrhoidectomy, a surgery to remove hemorrhoids, compared psychological and physiological measures between those given live plants for their rooms and those without live plants during their postoperative recovery period. Incredibly, looking at plants during recovery created a positive attitude about health outcomes of the patients. Plants and flowers produced significantly more positive physiological responses such as "lower blood pressure and lower ratings of pain, anxiety, and fatigue" than that of patients without plants. Patients with plants also reported more satisfaction with their rooms, noting that the plants made the environment brighter, decreased stress, and gave positive impressions of the hospital workers' care for them. Plants showed to have therapeutic value in the hospital environment as a "noninvasive, inexpensive, and effective complementary medicine for surgical patients." As helpful enhancing elements in hospitals, plants can turn a bedroom into a healing space. Though they are not a cure on their own, the contribution plants have to overall experience within a room and the feelings they produce are powerful in times of worry and as a result can produce real physiological benefits, which gives every reason to invite an indoor plant into the home, office, hospital, and beyond.

HortTechnology (2019). DOI: 10.21273/HORTTECH04427-19
Journal of Physiological Anthropology (2015). DOI: 10.1186/s40101-015-0060-8
Journal of Alternative and Complementary Medicine (2009). DOI: 10.1089/acm.2009.0075

PHOTOS BY KINDPNG

THE EQUATION FOR HOW FLOWERS BLOOM

BY ABIGAIL POTTER, PHYSICS & PHILOSOPHY, 2023

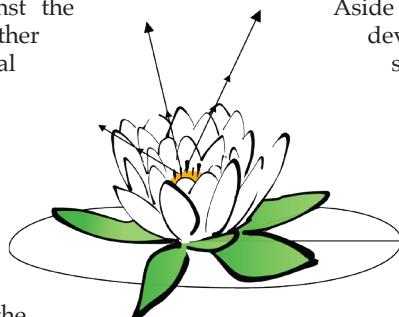
There are few things more poetic than a flower blooming. Artists clamor to capture graceful petals peeling back into a blossom, yet despite mankind's affinity for flora's beauty, little is known about how it comes to be.

It was initially suspected that petals would bend outwards because of internal stress building against the midrib (the central vein) of each petal. Another theory was that the inner face of each petal grew faster than the outer face, eventually causing the petals to bend back into their beloved blossom shape. However, a 2011 Harvard University study of an asiatic lily (*Lilium casablanca*) observed that neither theory seemed to be true, suggesting that flowers have another catalyst for blooming.

By observing how the cells at the edges of the petals grow quicker than those in the middle of the petals, researchers discovered that this uneven growing pattern creates a strain that's primarily responsible for the lily's extraordinary form. The strain is even visible to the naked eye, as the edges of the petals seem to ruffle in the wind while the center and base maintain a stiff shape.

The researchers created a mathematical formula to determine how the lilies bloom, giving a quantitative analysis to something once purely aesthetic. While it has been long accepted that petals and leaves share common evolutionary

origins, the formula shows that the structures of both develop quite similarly, despite the formula only being applicable to lilies. Leaves and petals both grow more at the edges, as shown by the ripple effect on their rim, but one difference between the two is that petals are nearly always naturally curved.



Aside from elucidating biological history, the development of the "blooming formula" suggests new ways of controlling elastic sheets and film and also assists with design development, especially for tools that mimic blooming. Actuator bimorphs, components of machines that move a system, can move more efficiently by replicating the bend of flower petals. This improvement can be applied to developing artificial muscles and soft robotics.

While the average person does not dissect art to discover the reason behind its beauty, there is no reason it cannot be quantified. With the Golden Ratio, architects have been creating art with mathematics for decades. The equation for a flower blooming similarly connects artists and scientists to fully appreciate the beauty of a flower in bloom.

Macromolecular Materials and Engineering (2019). DOI: 10.1002/mame.201800688
PNAS (2011). DOI: 10.1073/pnas.1007808108

DESIGN BY EVAN DIAZ, ARCHITECTURE, 2025

PHOTO BY PIXABAY

Mush-room for improvement

Harnessing the powers of fungi and technology

BY NICOLE KLEINBERG, CHEMICAL ENGINEERING, 2023

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

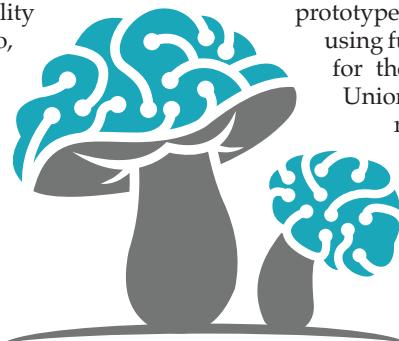
Our world is embracing smart technology, especially those available to consumers like a Fitbit or an Apple Watch. Smart wearables are everywhere, and most people have or know of someone who has at least one form of them. Although smart wearables are at the forefront of everyone's minds, what if we thought about them in a different way?

A collaboration between the University of the West England, Bristol; the Open University of Catalonia; the Italian Institute of Technology in Turin; and Mogu Srl ("Srl" is the Italian equivalent of a limited liability company in the United States) in Inarzo, Italy cultivated an improved version of smart wearable technology. Their research paper, "Reactive fungal wearable," details and describes how *Pleurotus ostreatus*, a variety of oyster fungus, has an ability similar to smart wearables in that they are able to sense and adapt to their surroundings. They also learned that the fungus was able

to create complicated computational components that can implement a range of Boolean functions. Although research into the potentials of fungi interfacing with computational mathematics has just begun, *Pleurotus ostreatus* can overcome one of the limitations of current smart wearables because of its self-repairing qualities as a live fungus.

One of the major conclusions of the study was to further research and applications about combining live fungi and electronics to make future smart wearable technologies. There is another ongoing study that streamlined the prototype depicted within the paper and expands into using fungal material that can sense the environment for the construction of buildings. The European Union-funded FUNGAR project hopes to use this research to develop a substance made out of live fungi, nanoparticles, and polymers that can be used in a future large-scale construction project. There is hope for more sustainable and functional smart devices and buildings in the future.

PHOTO BY SHUTTERSTOCK

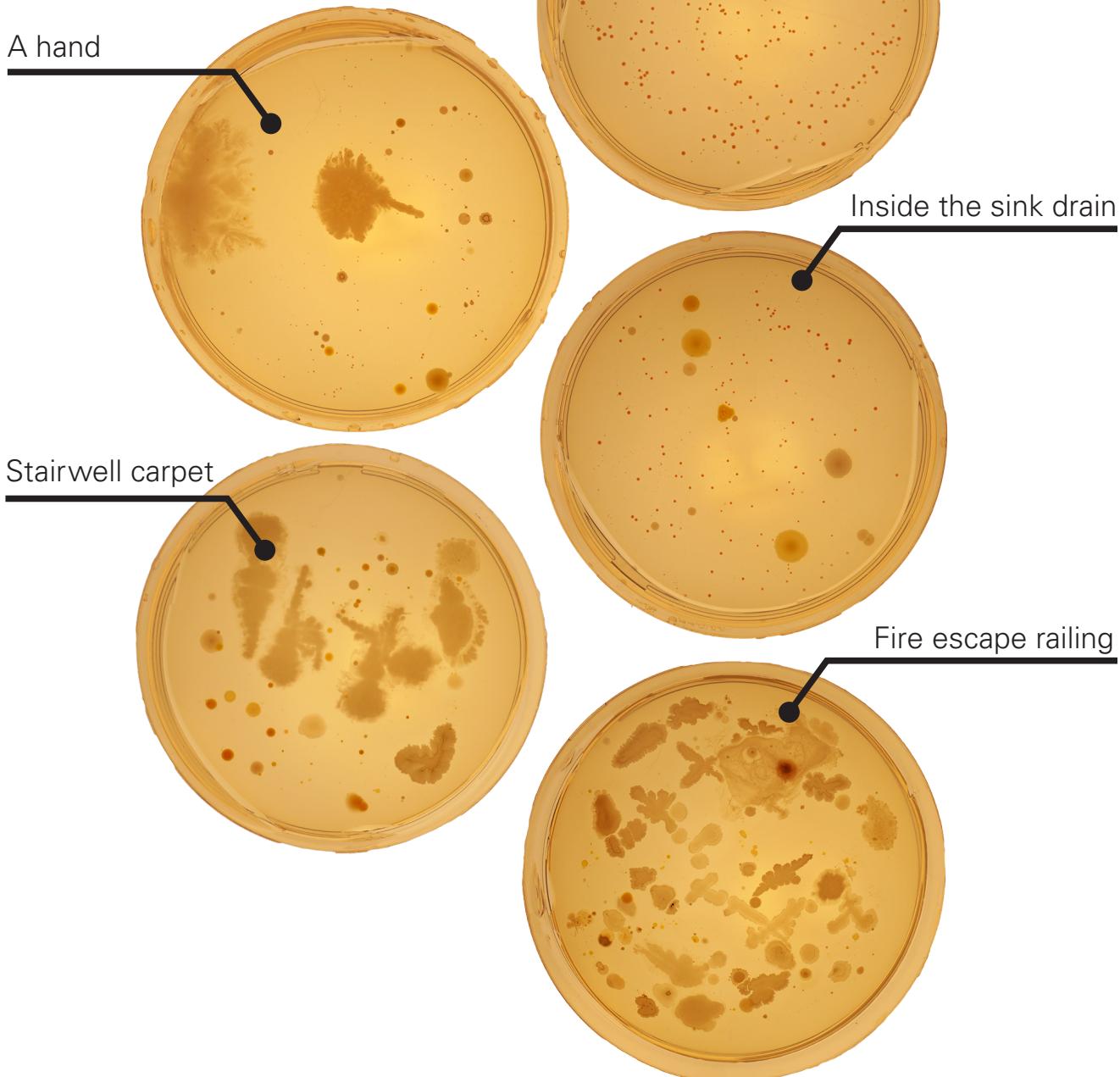


Biosystems (2021). DOI: 10.1016/j.biosystems.2020.104304

What's growing in your apartment?

Have you ever wondered how many kinds of bacteria are in the microverse around you? Remember, not all bacteria is harmful! In this period of constant hand sanitizing and cleaning, *NU Sci*'s heads of design swabbed some locations in their apartment to find out what is growing where. Count the colonies, or note the varying colors and shapes!

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

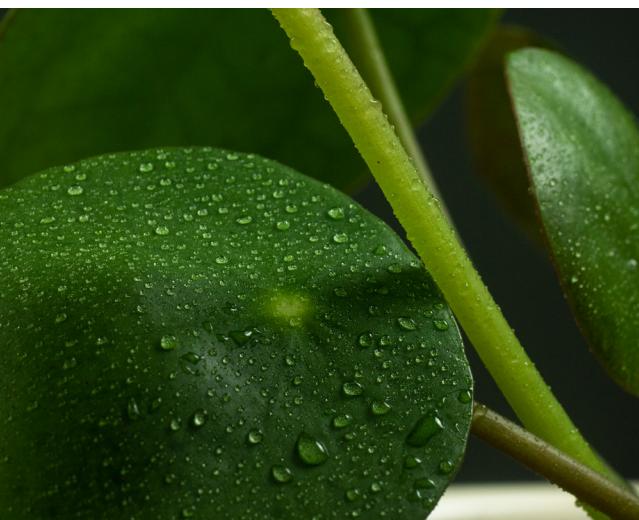




From succulents to foliage plants, greenery can make an indoor space healthier. A study by NASA has indicated that houseplants might improve indoor air quality by lowering concentrations of CO₂ and volatile organic compounds in classrooms. Having a plant around can both brighten up a home and keep it healthier!

J Toxicol Environ Health A. (2012). DOI:
10.1080/15287394.2012.721169

PHOTOS BY GUS MUELLER, MECHANICAL ENGINEERING,
2023



SENSING THE SEA:

Researching the adaptations of starfish

ARTICLE AND DESIGN BY RACHEL LINES,
BEHAVIORAL NEUROSCIENCE, 2023

Of all species living in marine environments on Earth, the relatively inconspicuous starfish may appear to live a simple existence on the seafloor. However, these organisms demonstrate striking abilities to perceive their environment, one of many characteristics that has led to their success as a species. This success is evident in their diversity — there are around 2,000 different species of starfish with widely varying appearances and sensory structures. One species known as the sunstar can even have up to 40 arms. This incredible diversity has attracted the attention of animal behavior researchers, who explore just how these fascinating creatures perceive and survive in their environments.

Although the average starfish appears to have a relatively simple anatomy of five connected arms, the physiological basis for sensation and perception in these animals is incredibly complex and often difficult to study. These senses include touch and chemical sensation, such as taste and smell. Fascinatingly, starfish are even capable of vision by using a compound eye structure present on the tip of each arm, and preliminary research indicates they may have some form of hearing and some form of detecting electrostatic and magnetic fields. The cumulation of these many sensory pathways makes it challenging to isolate a single sense through physiological and behavioral experimentation.

Despite these experimental difficulties, vision is one of the more studied and most well understood senses that starfish possess. Their visual structure, known as an ocelli or eye spot, has two known cell types: pigment cells and photoreceptors. In combination, these cells compose optical units, or ommatidia, and are thought to create one pixel each for an image. For several species of starfish, including blue sea stars and crown-of-thorns starfish, their visual sense has been optimized

for immobile red and green structures. These colors match the red and green coral boulder habitat that a starfish would experience in their day-to-day environment. Furthermore, the location of the eye spot at the end of each arm allows starfish to shift and stabilize their gaze by bending the tips of their arms during a general arm movement. This ability is what allows the starfish to perceive the surrounding environment and navigate difficult terrains.

Although starfish vision is well researched, other sensations are more challenging to study. For example, starfish chemosensation, which refers to the animal's ability to perceive chemicals through taste or smell, is a more difficult sense to isolate.



Researchers have long since debated over which cells are required for chemosensation and where these cells are located. Furthermore, if the suspected chemosensitive cells are removed, some researchers argue that other sensations may also have been eliminated through unintentional damage, complicating the results of the study.

Despite these challenges, the sense of smell in starfish can be assessed behaviorally through analysis of foraging behavior. Researcher Juan Castilla at the Pontifical Catholic

University of Chile used this experimental approach to study olfaction and prey-finding behaviors. Starfish were placed into y-shaped mazes, and researchers examined their ability to locate prey animals or food-related chemicals. A starfish was placed at one end of the y-shaped maze and a food item at the other. The sea star's ability to locate the prey was then analyzed under varying conditions to examine its sensation of prey chemicals. Another technique to learn about the organism's olfactory capabilities is to investigate specific receptors in the olfactory system, identifying and characterizing the physical and molecular mechanisms at play.

Beyond learning about the fascinating capabilities of starfish and the molecular basis for perception in these species, there are important applications for this knowledge. Crown-of-thorns starfish are the primary biological effector for coral cover loss to the Australian Great Barrier Reef. One way to protect these reef systems is to utilize knowledge of starfish sensory sensation to develop methods for population control. From foraging to reproduction, olfaction is essential for the survival of starfish species like the crown-of-thorns, so knowledge regarding olfactory receptors is useful to control the spread of this particular starfish population. In this way, research regarding starfish sensation serves a vital role in preventing further damage to a beautiful and delicate ecosystem. Not only is the research regarding these surprisingly capable organisms is beyond fascinating, it is also incredibly relevant for the protection of many of the valuable and magnificent locations on Earth.

BMC Genomics (2017). DOI: 10.1186/s12864-017-3793-4
Integrative and Comparative Biology (2017). DOI: 10.1093/icb/icx086

PHOTO BY PIXABAY



THE SUB-TWO-HOUR MARATHON:

An optimized storm of science and grit

BY SAGE KUMAR, BIOLOGY, 2023

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Four minutes and thirty-four seconds. That was Eliud Kipchoge's smile time...for 26.2 miles. On October 12, 2019, the acclaimed Kenyan distance runner broke a barrier that was once thought to spell certain death: a sub-two hour marathon. While rules on pacing and fluid allowance and concerns surrounding equipment engineering prevented his run from being counted as a world record, Kipchoge's time of 1:59:40 and unquestionable toughness will leave a permanent impact on the running world.

How did he do it? To start off, this feat was not the work of one sole runner. Kipchoge was accompanied by a rotating group of pacers, which included world-renowned athletes who all had a heightened awareness for pace, effort, and form. The squad ran in an inverted V formation, with Kipchoge sheltered from physical drag, the psychological burden of leading a race alone, and physiological resource depletion. This formation corresponds with findings dating back to Griffith Pugh's 1971 physiology study in which a 65-kilogram athlete's maximum rate of oxygen consumption increased from 3.01 to 5.01 liters per minute when subjected to 18.5 meters-per-second winds while running a standard marathon pace of 6 minutes per mile. Kipchoge was also assisted by bike-delivered fluids like water and electrolytes as opposed to the traditional run-by tables stocked with supplies, cutting seconds off his run by eliminating the need to deviate from the shortest span of the course.

As far as environmental conditions go, Kipchoge's experience was also optimized. The INEOS 1:59 Challenge in Vienna, Austria was held just for him with the venue and course reserved for a number of days to maximize the chance for ideal weather. On the day of the legendary run, the temperature hovered between 5 to 9 degrees Celsius with humidity below 80 percent and minimal wind — right within the preferred range for faster runners like Kipchoge, who generate larger amounts of heat while performing. Vienna is located a mere 156 meters above sea level, a staggering improvement to oxygen availability compared to Kipchoge's 2400-meter-high training camp in Kenya. The course itself was structured to minimize climb and turns, as right angles have been found to add an average of one second apiece to a runner's marathon time, and was also

lined with trees to further reduce drafts that could work against the runners' momentum.

The most controversial aspect of this race, and the one that leaves the sports world with the most questions, were Kipchoge's shoes. Kipchoge wore a prototype of Nike's AlphaFly. The stiff carbon plate embedded in the shoe's midsole has been employed in marathons before this one, and raises concerns about so-called "mechanical doping." A 2017 study was conducted regarding the performances of 18 athletes during a 5-minute trial run with and without the assistance of a carbon midsole. The addition of the carbon plate technology lent an average 4 percent decrease in energy exertion, measured through oxygen uptake and respiratory exchange ratios. When equalized for weight, a prototype of the Nike VaporFly shoe gave all the runners an energy advantage because of its ability to return the force exerted back to the athlete through recoil of the midsole. This raises questions that will come to influence the future of running and will exist in the world of sports for years to come. Will technologies like these become patented and owned by select companies, creating an unfair advantage for certain athletes and causing equipment bans like that of the Speedo tech suits in swimming?

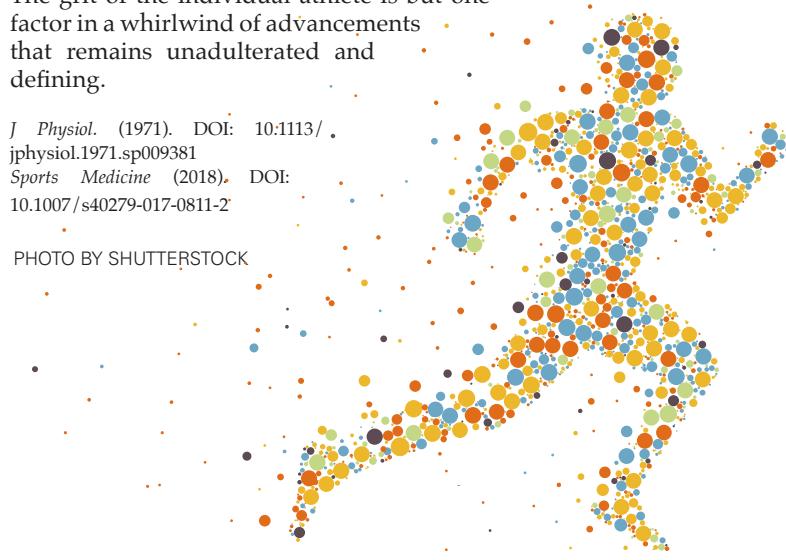
Or will they positively contribute to the revolutionization of sport by

becoming commonplace across manufacturers? And how will we determine the competition legality of technological, nutritional, and medical advancements regarding sport as we continue to innovate? The answers to these queries remain foggy, but one thing is certain: Kipchoge himself deserves much more credit than this article has given him. The grit of the individual athlete is but one factor in a whirlwind of advancements that remains unadulterated and defining.

J Physiol. (1971). DOI: 10.1113/jphysiol.1971.sp009381

Sports Medicine (2018). DOI: 10.1007/s40279-017-0811-2

PHOTO BY SHUTTERSTOCK



The tales of conjoined twins

BY BEIYU (PAM) LIN, BIOLOGY, 2021

DESIGN BY SOPHIE PATE, ARCHITECTURE & DESIGN, 2024

Abbey and Brittany Hensel are conjoined twins, a medical phenomena in which two babies are born anatomically connected to one another. The sisters shot to fame in 2012 when they became stars of their own reality show, titled “Abby and Brittany,” which detailed their interconnected journeys as they graduated college and attempted to establish their careers. While the Hensels are what is medically known as dicephalic parapagus twins, a form of partial twinning in which each twin has their own head but shares a torso, the range of conjoined twins is vast. Simple conjoined twins may only be attached by skin and cartilage, whereas more complicated cases can share a brain and other vital organs.

In Abby and Brittany’s case, the sisters share many organs, including legs, arms, liver, bladder, and reproductive organs, but each have their own hearts, lungs, and stomach. There is clearly a profound clinical impact of this medical condition, so how exactly does it arise?

Conjoined twins form when an early embryo does not fully separate to form two individuals, resulting in two fetuses that remain anatomically connected. Separated identical twins are created when a fertilized egg splits approximately 8 to 12 days after conception, allowing for the development of individual organs. The running scientific theory is that when the fertilized egg splits later than intended, the separation is halted early and results in a pair of physically connected fetuses. While many conjoined twins unfortunately are stillborn or are unable to survive their first few days of life, others can go on to live connected lives, such as Abby and Brittany, or can be surgically separated depending on medical risk.

In October of 2020, there were remarkable reports on the surgical separation of nine-month-old conjoined twins at the UC Davis Children’s Hospital. Abigail and Micaela Bachinskiy are an even rarer form of conjoined twins known as craniopagus twins, meaning they were connected at the head. The surgeons decided that they needed to separate the twins immediately, seeing as waiting any longer would

create higher medical risk when their organs grew larger. Thus, they performed a successful 24-hour procedure, which consisted of dividing brain matter, veins, and five total position changes.

Other stories of conjoined twins are not as heartwarming as Abigail and Micaela’s. In 1811, Chang and Eng Bunker were born in Siam (presently Thailand) and went on to become the first set of well documented conjoined twins and inspiration for the antiquated term “Siamese twins” because of their birth country. In

1824, a British merchant took the boys to the United States to create a worldwide exhibition of them in exchange for public fees; this propelled the twins to gain worldwide fame for their medical condition. However, in 1874, Eng woke up one morning to find that Chang had died in his sleep as a result of a cerebral clot. Before a doctor could arrive to attempt a separation surgery, Eng had apparently already died of fright.

While the many stories of conjoined twins may attract natural human curiosity, it’s critical to remember that the lives of conjoined twins are often filled with many medical and social disadvantages. For a pregnant mother, the presence of these twins greatly increases the risk for serious complications. The twins themselves are often born prematurely and are more likely to go on to experience breathing difficulties, heart problems, cerebral palsy, and learning disabilities. In addition, unseparated conjoined twins are much more susceptible to an array of personal issues, such as the fear of lacking a personal identity and repercussions from any stigma surrounding the condition. Today’s amazing medical advances make the possibility of surgical separation much more accessible, yet the execution of these procedures still may prove to be too high risk in certain cases where vital organs are connected. Whether conjoined twins are able to separate and live individual or interconnected lives, the hope is that today’s world allows them to live flourishing and full ones.

The Tohoku Journal of Experimental Medicine (2005). DOI: 10.1620/tjem.205.179



Magnetic growth in the nervous system

BY AMANDA BELL, DATA SCIENCE & BIOLOGY, 2023

The brain, arguably one of the most complex organs in the human body, has more difficulty repairing itself than most other parts of the body. While the nerves outside the brain and spinal cord, which make up the peripheral nervous system, regenerate automatically, the central nervous system, which consists of the brain and spinal cord, has greater difficulty regenerating. The fact that the central nervous system has difficulty repairing neurons is part of the reason why neurodegenerative diseases, like Parkinson's disease, are so debilitating. However, not all hope is lost.

II The fact that the central nervous system has difficulty repairing neurons is part of the reason why neurodegenerative diseases, like Parkinson's disease, are so debilitating."

Researchers have discovered a signaling molecule that can enhance neuron regeneration after injury: H-RAS. When overexpressed in mouse neurons, H-RAS helps with the regeneration of axons, the part of the neuron responsible for relaying signals across the cell to the axon terminals that then transmit these signals to other cells. However, for axons to regrow, H-RAS needs to be positioned in a specific way so that signaling is focused in the axonal growth cone, which is the machinery responsible for axon extension. Typically, an overexpression of proteins in the MAPK/ERK pathway prevents the optimal positioning of H-RAS. The MAPK/ERK pathway is not only associated with axonal growth but also with the differentiation of neurons and apoptosis (programmed cell death). Fortunately, the remote control of magnetic nanoparticles might be able to overcome this obstacle, allowing for optimal axon regeneration.

Since magnetic fields can safely penetrate deep tissue and control cell behavior, magnetic nanoparticles can be applied in the brain. Scientists explain that applying a magnetic field attracts nanoparticles, thereby generating a "mechanical stimulus" that induces neurite outgrowth and axon



DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

extension. A neurite refers to a developing neuron which has not yet developed axons or dendrites, as well as any projection off of a neuron, such as an axon or a dendrite. For a mechanical stimulus to be generated, researchers have used vesicles to get nanoparticles into the cytoplasm of cells. Even with this application of nanoparticles, however, the axons may not be stretched long enough to bridge disconnected brain regions to treat neurodegenerative diseases.

In order to stretch axons far enough, the scientists suggest putting nanoparticles directly in the cytoplasm rather than in cell vesicles. The researchers started by tagging H-RAS and another protein called SOS1 so that the magnetic nanoparticles could bind to them. Once the nanoparticles were bound to the tagged proteins and a magnetic field was applied, the protein-nanoparticle compounds moved to the tips of the neurite so that the growth cone could elongate and an axon could grow. The researchers tested their methodology in rat tumor cells that have the ability to differentiate and become full-fledged neurons with axons and dendrites. Nerve growth factor was added to ensure cell differentiation and to further stimulate growth. Since no toxic effects were observed when scrape-loading the cells with the magnetic nanoparticles, longer-term magnetic treatments of two days or more will be tested in the future. The main goal of this study was to get the neurons of Parkinson's disease research models loaded with the magnetic nanoparticles. These models will help researchers perfect this technique so that the neurons can one day be transplanted into people with Parkinson's diseases as treatment.

Although there is still a long way to go before neurodegenerative diseases become curable, the use of magnetic nanoparticles provides hope that a cure is possible. For a long time, scientists thought it was impossible for neurons of the central nervous system to be regenerated. However, with the force of magnetism, it has been proven that growth can be stimulated in the nervous system.

Scientific Reports (2020). DOI: 10.1038/s41598-020-80253-w
Journal of Neuroscience (2020). DOI: 10.1523/JNEUROSCI.3075-19.2020
PNAS (2011). DOI: 10.1073/pnas.1011258108

PHOTO BY SHUTTERSTOCK

Fruit that lasts forever!

How gene editing may answer the problem of postharvest waste

BY GABRIELLE HERNANDEZ, BIOCHEMISTRY, 2023

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

Crisp apples, plump tomatoes, juicy berries, and citrusy oranges are endless luxuries in the middle of Boston's cold, dead winter. Despite slush and ice covering grass and sidewalks, grocery shelves are fertile with everyone's favorite produce. However, the fresh fruits and vegetables that fill the aisles involve a lengthy journey and intense science to get avocados and limes to frigid New England. Moreover, 33 percent of that produce is thrown away after harvest in the trek from farms to shelves to our homes.

The intentionally discarded produce is called postharvest waste, a growing, worldwide concern. This occurs as a result of the consumer's desire for the best product. This means casting aside bruised peaches, bad apples, and cracked tomatoes, although they are perfectly edible. In a review published by *Nature's Horticulture Research*, researchers at the University of California, Davis analyzed the causes, impacts, and solutions to postharvest waste. Why does perfectly edible produce get thrown away by grocery stores, and how can it be preserved?

It starts with the general public lowering their standards. "Perfection is not something that should be applied to fruits and vegetables," said Dr. Diane Beckles, a postharvest biochemist and study author. "There is an element of capitalism that influences the produce market, where we have unrealistic expectations based on what we see on TV or in paintings or cartoons of what fruit and vegetables are supposed to look like ... There are going to be imperfections, blemishes, and variability in the quality."

But can consumers have these high expectations for their produce when it travels thousands of miles across a highly extensive supply chain to meet their shelves? As Beckles and her colleagues highlight, these supply chains can last months. Although fresh, perfect produce cannot withstand that timeline, there are many methods by which the produce is preserved to attempt to meet the expectations of the consumer.

Ethylene is one hormone produced after harvest that creates the tastes, textures, and flavors that we love in ripe fruit, but it also causes the produce to age and senesce. This results in unfavorable bruises and blemishes on the invaluable fruits and vegetables as they travel along the supply chain.

"Ethylene is a friend and a foe," Dr. Beckles underscores. "If you want to be able to control the shelf life of some produce, then you have to be able to manage ethylene."

Ethylene production is targeted by many elements in the supply chain that are used to regulate the

environment of the produce. It can be managed through metabolic inhibitors, temperature control, and coatings throughout the produce's postharvest timeline. But the study authors propose a different mode of action, using gene editing tools to regulate the production of these ripening chemicals. One common tool for controlling plant genes is CRISPR-Cas9, a microbe-based gene editing technology.

Although CRISPR seems like the answer to just about everything nowadays, there are still many challenges that this methodology faces. The authors of the review highlight the war over CRISPR patenting. The Broad Institute, located on the Cambridge side of the Charles River, currently owns the United States patent for CRISPR editing in eukaryotic cells, which applies to all produce. The University of California holds the same patent — but for Europe, China, Australia, and Singapore. Although these groups allow CRISPR research in academia, it constricts the work of private sector companies in increasing the lifespan of everyday produce.

“Moreover, 33 percent of that produce is thrown away after harvest in the trek from farms to shelves to our homes.”

Gene editing technology is also highly regulated throughout Europe, preventing many gene-edited crops from entering the market and therefore from reducing postharvest waste. Another roadblock in the path to long-lasting spinach is growing societal concern over genetically-modified organisms.

"People often think of it as an invasion of nature, but it's more like coaxing plant growth to be suitable for modern agriculture," detailed Dr. Beckles. "We humans have been doing this for the past ten thousand years."

In a world where food insecurity only grows with global climate change and overpopulation, it will be necessary to conserve and value the produce that is grown each year, using some of science's most innovative technologies. For Beckles and her group, this review was a necessary step to opening the conversation of postharvest waste.

"We wanted to educate the public about the severity of the problem," said Dr. Beckles. Proposing answers like CRISPR to improve the amount of postharvest waste illustrates that "there are practical solutions out there that can go a long way toward solving these complex problems."



Horticulture Research (2021). DOI: 10.1038/s41438-020-00428-4

PHOTO BY SHUTTERSTOCK

MICROBIOOME THE MAGIC OF THE

BY RYAN BRADY, CHEMICAL ENGINEERING & BIOCHEMISTRY, 2022

A common saying is that humans are made up of 60 percent water, but it is less commonly known that for every cell in your body there are up to 10 bacteria present as well. While they are generally thought to be harmful, mutualistic bacteria are essential for proper intestinal function. The group of microorganisms found in the gut is referred to as the microbiome. These organisms are crucial to the process of digestion. Many studies have found links behind the microbiome and diseases including irritable bowel syndrome and Parkinson's disease. It also could explain the side effects of antibiotics including abdominal pain, indigestion, and nausea. Based on this research, several supplements have arisen which claim to promote gut health. However, they are not FDA approved, so it is important to assess independently the impact of these supplements.

Some foods, such as yogurt, naturally contain probiotic bacteria that impacts the microbiome. In fact, the yogurt-making process utilizes live bacteria to ferment milk into yogurt. This process usually uses *Lactobacillus bulgaricus* and other bacteria, which are then present in the final product. Multiple studies have been conducted and connected frequent yogurt consumption with a decreased risk of cardiovascular disease, diabetes, and kidney disease. One study conducted by Daniel J. Liski et al. used advanced DNA sequencing techniques to evaluate the impact of a high-yogurt diet on the microbiome. The data showed a high variation between individuals, likely a result of environmental factors on the microbiome. However, their study also demonstrated a significant change in bacterial composition as a result of yogurt consumption but did not determine the impact of the change because there is little research on how individual microbes affect the microbiome. Further, the European Food Safety Authority concluded that the consumption of yogurts containing *Lactobacillus delbrueckii* and *Streptococcus thermophilus* can help alleviate lactose intolerance, since they contain bacteria to break down the lactose.

The importance of the microbiome has led to the prevalence of microbial supplements, yet little data exist supporting their efficiency. Since 2019, there have been thousands of scientific papers that discuss the relationship between the microbiome and the host, but this has not yet been translated into clinical applications. This is likely a result of the high degree of diversity within the microbiome. The Human Microbiome Project sampled 250 volunteers and found between 3,500 and 35,000 species of bacteria per person. Further, because of the nature of bacteria, the amount of genetic information contained within them is about 150 times that of humans. This difference, along with the high genetic diversity within bacterial families, makes it extremely challenging to deduce the role of a specific species within the body. While certain supplements may benefit people with certain conditions, the lack of consistency and understanding of the mechanisms of action prevents probiotic supplements from being FDA approved. Therefore, as a potential consumer, it is important to understand that commercial probiotic supplements have been proven safe to consume but not proven to be effective.

Overall, the microbiome is an essential part of how the human body operates, in which dysfunction can contribute to several prevalent diseases. Because of the known prevalence of bacteria in the gut microbiome, a number of products contain probiotics to supposedly boost microbiome health. These claims are extremely hard to validate as several environmental factors result in a large amount of variability both within a single microbiome and between individuals' microbiomes. Yogurt has been proven to assist with lactose digestion as well as decrease risks for a number of diseases. While current research indicates the importance of the microbiome, further research will hopefully better characterize it for treatment and supplementation.

HOW CELLS ORCHESTRATE THEIR DEATH

BY LIAM O'MALLEY, BIOCHEMISTRY, 2023

You may have heard of some eye-catching statistics like “every seven years, every cell in your body has been replaced” or “every day, 50 billion cells in the human body die,” and these are true. Cells within the body are constantly multiplying as you grow, as part of maintaining homeostasis. However, what you might not know is exactly how these cells are replaced. The vast majority of this cell death is, by design, occurring by a natural process termed apoptosis.

Apoptosis — also known as programmed cell death — is the process by which old or diseased cells are naturally killed to pave the way for new cells. This differs importantly from necrosis, which is cell death that results directly from injury or disease. Programmed cell death is just that — programmed. There are a few well-regulated and controlled steps along one of two pathways that must occur before the irreversible process is started.

The first pathway is the intrinsic pathway. This is almost always instigated by some stressor, such as heat, radiation, hypoxia (lack of oxygen), or lack of nutrients. It can also be started by a high concentration of certain ions or molecules like calcium or fatty acids. If any of these conditions are sensed by regulatory proteins in the cell, they can send along a signal through a cascade of messenger proteins. This signal can be stopped if it is determined that the cell no longer needs to die (perhaps a cell previously undergoing hypoxia is now oxygenated). The message is sent toward the mitochondria, the essential, energy-producing organelles of the cell.

Once the mitochondrion is reached, the process of death begins. While apoptosis can be initiated by a number of various signals, the most common pathways all begin by increasing the permeability of the mitochondrial membrane.

In a healthy cell, the mitochondrial membrane maintains a gradient of protons on one side, which drive its energy-making capabilities. If the membrane is made more permeable, this gradient is lost, and the potential to create energy drops drastically. The mitochondrion will then begin to secrete molecules that speed along the apoptotic process. These molecules, called SMACs (second mitochondria-derived activator of caspases) recruit caspases, a certain class of enzymes that break down proteins, to digest much of the cell, leaving the rest to white blood cells. These enzymes break open the cell like a piñata, releasing its contents and leading to its demise.

The extrinsic pathway takes a slightly different approach. On the exterior of the cell membrane, there are two receptors

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

that take part in inducing apoptosis: the TNF (tumor necrosis factor) and Fas receptors. Certain signaling proteins from elsewhere in the body can bind to these receptors, forming the death-inducing signaling complex (DISC). This complex then promotes the activity of caspases, which finish the job.

Despite apoptosis primarily being used to clear away dead or diseased cells, it is also a useful tool in both fetal development and overall growth. In the womb, the fingers and toes of a fetus grow first as a mass of cells. Careful apoptosis of certain cells allows each finger to be separated once they’re large enough. Apoptosis functions almost as a controlled demolition to pave the way for more refined growth.



Despite apoptosis primarily being used to clear away dead or diseased cells, it is also a useful tool in both fetal development and overall growth.”

While apoptosis is often used to promote growth and prevent the accumulation of weakened or dead cells, it can also be combated by tumors, leading to too many cells staying alive when they shouldn’t. Certain, carefully regulated processes within apoptosis can mutate and wreak havoc on the previously well-controlled system. In many cancers, inhibitors to various parts of the signaling cascades are overexpressed, preventing apoptosis from occurring. This allows the tumor to grow despite parts of the body signaling for it to be destroyed. It’s quite hard for the body to fight off a tumor when it literally can’t pull the trigger.

Despite cancer’s effective mechanisms of defense, there are some promising avenues of research within the apoptotic pathway. For example, researchers have been investigating creating their own apoptosis-inducing ligands to bind to the external TNF and Fas receptors to artificially create the DISC. Many times, the questions these scientists are studying boil down to how to enable cancerous cells to kill themselves, and at the end of the day, that’s all apoptosis is — it’s the basic mechanism of inducing death to allow for more life.

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Your gut is a garden — for bacteria:

Bacterial blooms and their link to neurological conditions

BY HIBA HUSSAIN, BIOLOGY, 2024

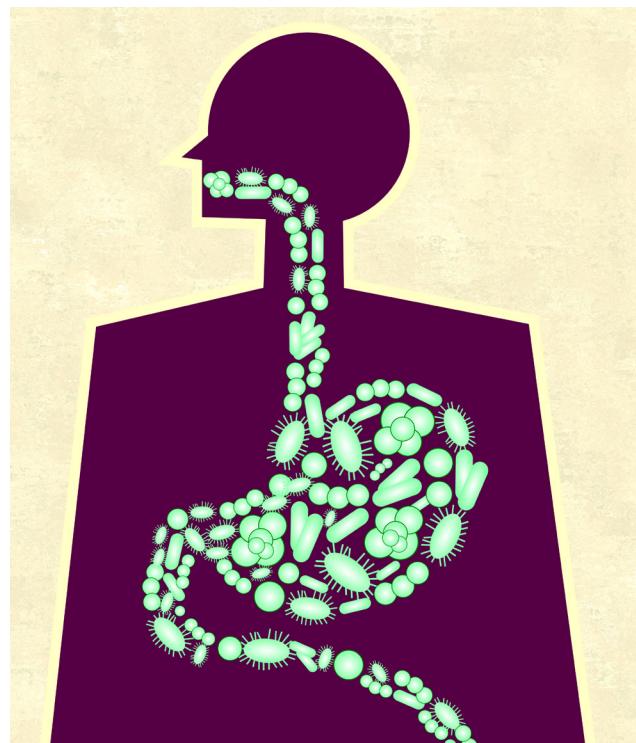
DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

Next time you feel lonely during this time of social isolation, just remember you always have 100 trillion friends. Why? Because you aren't *really* alone. As you read this, there are 100 trillion microorganisms who call your digestive system home and are dedicated to keeping you healthy. Contrary to popular belief, not all strains of bacteria cause illnesses like food poisoning or Salmonellosis (*Salmonella* poisoning). In fact, strains like *Lactobacillus* and *Bifidobacterium* (commonly known as probiotics) have been linked to health benefits for a range of conditions like atopic dermatitis, irritable bowel syndrome, and hypercholesterolemia.

A recent field of study demonstrates that a lack of diversity in the gut microbiome may cause health conditions, namely neurological ones. In 2006, Jane Foster and her team at McMaster University made a pioneering discovery in this area. When Foster compared mice with a healthy collection of gut microorganisms to those who lacked them, she noted that the mice seemed less anxious than their healthy counterparts. This initial finding began a flood of research regarding how the connection between the gut and the brain is controlled by the gut microbiome. Through studies in mice and the beginnings of human studies, scientists have now determined possible connections between the presence of certain gut microbes to neurological conditions such as Autism and Amyotrophic Lateral Sclerosis (ALS). Therapies to modify the microbiome could potentially prevent or stop the progression of certain diseases with some initial testing in human clinical trials already underway.

Gloria Choi, a neuroscientist at MIT, and Jun Huh, an immunologist at Harvard Medical School, have made eye-opening discoveries regarding the connection between Autism and the gut microbiome. In past work, a greater chance of Autism diagnosis has been linked to an infection during pregnancy. Choi and Huh wanted to determine the cause of this correlation, so they triggered the mice's immune response to act as if their bodies were exposed to an infection. They found that a type of bacteria called filamentous bacteria affected T-17 helper cells, which are essential for the adaptive immune response. The cells became overactive and produced IL-17, a molecule important for cell signaling. These IL-17 molecules moved through the mother's placenta and into the brains of the pups by binding to a neural receptor, resulting in neuroatypical activity in the newborns. To see if removing these filamentous bacteria would make a difference in newborn health, the researchers targeted the bacteria with an antibiotic and then triggered a similar infection in the mice. Surprisingly, the T-17 helper cells didn't produce IL-17, and the pups exhibited neurotypical traits. Choi and Hun are currently working to determine if SARS-CoV-2 infection (COVID-19) can cause changes in the maternal gut microbiome, increasing the chance of neurological conditions like Autism.

Recent research has determined that modifying the gut microbiome can significantly impact the progression of neurological diseases such as ALS. Eran Elinav, a scientist



at Israel's Weizmann Institute of Science found stark differences in the progression of ALS from one patient to another and wondered whether the microbiome could explain such differences. In order to test his theory, Elinav worked with ALS mice models and found that if he cleared a mouse's gut of its microbiome, ALS would progress more rapidly than in a mouse with a normal microbiome. In determining a supplement for the mice lacking a microbiome, Elinav sought out which products of bacteria, also known as bacterial metabolites, came from mice with a normal microbiome. Elinav and his team analyzed vitamin B3 (nicotinamide) and administered supplements to the mice, finding that the vitamin B3 molecules travelled to their brains and led to slower development of ALS symptoms. Vitamin B3 is currently being offered as a supplement to ALS patients in a clinical trial, and Elinav and his team hope to further investigate more bacterial metabolites for different neurological conditions in the future,

The future of personalized medicine is changing and alternative treatment options for conditions that were death sentences in previous generations are gradually becoming a reality. With the ability to modify the gut microbiome, there is a possibility that genetics will play less of a role in determining the outcomes of one's health. As a result, patients will have more ownership of their health, placing the burden of responsibility on themselves, which is powerful, but also a little scary to think about.

Nature (2019). DOI: 10.1038/s41586-019-1443-5
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Nature (2021). DOI: 10.1038/d41586-021-00260-3

A CLOSER LOOK AT TRANSPARENT ANIMALS IF ONLY WE CAN LOOK!

BY SOUMILI DEY, CELL & MOLECULAR BIOLOGY, 2024

DESIGN BY YECHAN YANG, BIOLOGY & PSYCHOLOGY, 2022

Upon first sight, transparent animals seem like ethereal creatures from alternate dimensions of the universe. However, thousands of species of transparent animals inhabit regions all across the world — mainly in marine habitats. These animals lack pigment, allowing light to pass through them and scatter instead of reflecting, which gives them their transparency. From the glass octopus to the glasswing butterfly, transparent animals form an intriguing niche in the fauna of Earth. They resemble their opaque relatives closely but remain distinguished from them in many ways.

One of the primary skills any wild animal needs is survival. Camouflage has been a survival technique for a multitude of animals both on land and underwater. In the ocean, animals that live near the surface of the water use a technique known as counter-illumination that allows them to reflect light to resemble sunlight. Predators from below perceive them as sunlight on the ocean surface. Some other animals use sunlight to their advantage while camouflaging. Researchers Parish Brady and Molly Cummings at the University of Texas at Austin studied silvery fish, like the lookdown, which manipulates sunlight to camouflage. Through photographs, Brady and Cummings discovered that structures on their skin, called platelets, reflect sunlight better than many human-made mirrors.

In the deeper regions of the ocean, animals do not require camouflage because of the low light levels there. In between the lighter upper ocean and darker abyssal zone lies the pelagic zone. With few structures to hide behind, transparent animals evolved and thrive in this middle zone. However, these animals are not completely see-through. While the absence of pigment aids in transparency, the light's medium and angle of travel and the surface of the animal all affect the degree of light scattering. Additionally, transparent animals' eyes require light to penetrate them to be able to see, making it impossible for them to be completely invisible. The shadow of their eyes, other organs, or food consumed are often visible on the ocean floor, which makes them easy prey for deeper-swimming predators.

Animals have evolved to protect themselves, however. The glass octopus has elongated eyes that result in reduced peripheral vision and minimize the shadow cast on the ocean floor. The family *Cranchiidae*, comprising glass squids, has opaque eyes but possess organs known as photophores under their eyes that produce light similar to sunlight. Research conducted at the University of Pennsylvania

found that *Cranchiidae* adjust their emitted light to the sunlight at any given time, allowing them to reach their maximum level of transparency. Another technique to appear less conspicuous is deployed by the tomopteris deep sea worm; they release a glowing part of their bodies to distract predators.

Relying solely on reflecting light may not guarantee survival. Transparent animals' ability to reflect light may be taken advantage of by predators because they have rapidly adapted to use bioluminescence to hunt. Thus, hyperiid crustaceans use their nano-sized hairs and bumps to minimize light scattering. They are more vulnerable to predation because their outer surface is composed of chitin, increasing light reflection. In a study conducted on the effectiveness of nanostructures in reducing surface reflections, it was found that nano-sized hairs reduced bioluminescence reflection by around 100-fold. This is significant as even minor reductions in reflection can drastically increase survival rates of transparent animals.

Land animals typically do not have whole-body transparency. This characteristic can be attributed to the difference in refractive index of biological molecules and air. Refractive index is a measure of how fast light travels through a medium. Typically, light travels slower in denser molecules, like animal tissues, which increases chances of reflecting light. Even components of a cell — such as the mitochondria, nuclei, and lipids — have varying refractive indices. The difference in refractive indices of biological molecules and air is much larger than their difference with water. Because of this, transparency in land animals is restricted to a small part of their bodies — like in the glasswing butterfly. The butterfly's transparent wings have randomly-sized structures called nanopillars that cause most light rays to pass through without reflecting.

However, there are times when transparent animals gain momentary opacity. Environmental or physiological stress may force an animal into gaining opacity like in the case of the ghost shrimp. In increased temperatures or increased salinity, hemolymph rushes to their intermuscular space to lower their scattering of light.

While transparent animals have adapted their appearance, survival techniques, and habitat, their transparency inspires many more questions whose answers are yet to be found.

VIRUSES BURIED IN YOUR DNA

BY EMILY CHEN, DATA SCIENCE & BIOCHEMISTRY, 2023

DESIGN BY SOPHIE PATE, ARCHITECTURE & DESIGN, 2024

In a rapidly changing world, some may take comfort in the constants; however, it has become apparent that even our DNA may be on the move. Recent studies have shown that the human genome contains roughly 100,000 pieces of endogenous retroviruses (ERVs), making up about 8 percent of our genome. ERVs are pieces of DNA that are of viral origin. When a person is infected, the virus has the potential to alter human DNA by adding some of its own genetic material (RNA) to it, and that RNA can be passed down through generations. The implications of viral DNA — if they have the ability to replicate or reproduce — are unknown. Some ERVs can be linked to cancer and pregnancy; however, the functions of the majority of ERVs are still being explored.

The function of ERVs can have both beneficial and harmful effects on humans. For instance, in the 1900s, certain ERVs were discovered to have pathogenic effects as transmissible agents of cancer. On the other hand, they can benefit the health of a developing fetus, as an ERV helps build a cell layer around it, providing protection from toxins in the mother's blood. Most of the ERVs discovered are no longer functional; however, the exploration of their potential has revolutionized immunology studies by creating vaccines, precautionary measures for cancer, and new ways for scientists to better understand cancer biology.

Most ERVs discovered were because of their similarity to modern viruses, but scientists have hypothesized that not all ERVs share those attributes. These viruses have not been identified by conventional techniques and have most likely gone extinct or are unknown. They can unlock a new wealth of knowledge as scientists explore the mechanisms viruses utilized in the past and how they affect viruses in the future.

" ERVs present scientists with the opportunity to explore how viruses have evolved over time."

Computer scientists are looking at how to recognize more of these ERVs using machine learning techniques. One group of researchers used a machine learning algorithm, focusing on one class of viruses to train their model. Using known non-retroviral RNA virus elements, the machine learning algorithm can differentiate between viral and non-viral DNA. When given the entire genome, the algorithm can identify all viral DNA. In a 2021 study, 100 potential pieces of viral DNA were identified. After filtering out false positives and viruses already discovered, researchers were left with a grand total of one ERV; this being said, the lone ERV has proven very valuable.

When examined, the newly discovered ERV was similar to an insertion site in chimpanzees and marmosets, meaning the insertion occurred about 43 million years ago. Moreover, there can be a wide range of ERVs in the human genome unlike any modern viruses. Discovering this novel ERV lead to the opportunity for computer scientists to find different ERVs by using viruses other than one specific class of viruses to train the machine learning algorithm or exploring the genome of other animals. The genomes of animals such

as bats and rats, known common vectors for disease, are starting to be explored.

The discovery of ERVs has revolutionized the fields of immunology and pathology. ERVs present scientists with the opportunity to explore how viruses have evolved over time. The use of machine learning to discover ERVs not detected by conventional homology techniques gives scientists further insight to the diversity of ancient and modern viruses.

PNAS (2016). DOI: 10.1073/pnas.1602336113
 PNAS (2021). DOI: 10.1073/pnas.2010758118

PHOTO BY PIXABAY

THE WORLD THROUGH THE EYES OF A PIGEON

BY KRISTINA KŁOSOWSKI, BEHAVIORAL NEUROSCIENCE, 2022

As humans, we often naturally fall into the assumption that the world around us exists exactly as we see it. In reality, it appears that we see the world very differently from some of our animal counterparts, and in some cases, our perceptions are quite limited in comparison.

The naked human eye can only detect a small section of the electromagnetic (EM) spectrum known as the “visible light” spectrum. The human eye has two different types of photoreceptor cells located in the retina called rods and cones. The cones are the cells that are responsible for supporting color vision. In humans, there are cone cells with three different photopigments: red-sensing, green-sensing, and blue-sensing. The combination of these cone cells is what allows us to distinguish between the different colors of the rainbow that exist on the EM spectrum. Though this range of vision was evolutionarily sufficient for us, some animals have far surpassed it.

Surprisingly, the pigeon is one of these animals. In addition to visible light on the electromagnetic spectrum, pigeons can also see ultraviolet light, which has a slightly



shorter wavelength. In fact, a pigeon’s vision can be so advantageous that the United States Navy once tried to use them for search and rescue missions, training them to signal when they spotted certain colors like those of a life preserver from a person lost at sea. Taken along on helicopter rescue missions, pigeons were able to spot their target 90 percent of the time, whereas the rescue crew was only able to spot the target less than 40 percent of the time.

Pigeons are far from being the only members of the animal kingdom with vision advantages. Another unlikely candidate, the mantis shrimp, has 13 more color receptors than humans. In addition to seeing a vastly broader spectrum of colors, mantis shrimps can detect polarized light, or light waves that only vibrate on a single plane. This allows their vision to be better suited to life under the ocean, where light reflected by the water causes more glare than experienced above ground.

These scientific discoveries in animal vision, often occurring by accident, spark curiosity about what the world really looks like just beyond our field of vision.

Dendritic polymers for dermal drug delivery

BY CAILEY DENONCOURT, BIOENGINEERING & BIOCHEMISTRY, 2022

Dendrimers, or chemistry’s snowflake, are complex polymers that have the potential for many drug delivery applications. Starting with a singular atom at its core, dendrimers are formed through the connection of layer upon layer of additional functional groups until a spherical macromolecule is created. Polymers are materials that are made of many repeating units, also known as monomers, that are linked together to form long chains, which can be linear or, in this case, branched and spherical.

Although these macromolecules are difficult to synthesize, researchers find them appealing for drug delivery because of some of their unique properties including water solubility, internal cavities, and uniform size. Since they are synthesized from the inner layer out, it gives scientists the ability to customize the surface functionality of the molecule. Often this entails a hydrophilic (water-soluble) outer layer and hydrophobic (water-repellent) center. With these properties, scientists are investigating its application for oral drug delivery, but more notably, transdermal (through the skin) drug delivery provides a new research avenue.

For most medications, oral drugs provide easy administration, but sometimes patients are unable to take drugs orally because of negative side effects or because some molecules are destroyed when exposed to the gut environment. Thus, transdermal drug delivery provides a promising alternative, since the skin is a relatively permeable surface. This will be especially helpful for many of the new hydrophobic drugs that have low water solubility. Instead, these drugs can be fitted into the internal cavity of a dendrimer and passively sent through the skin and into cells because of its outer hydrophilic nature.

The extent of using dendrimers for drug delivery is still currently being researched. Possible medication applications include anticancer, antiviral, and nonsteroidal anti-inflammatory drugs. However, they are highly difficult and expensive to make, so before these can be mass implemented, chemists will need to continue to reduce the cost of these polymeric drug delivery capsules.

Therapeutic Delivery (2017). DOI: 10.4155/tde-2017-0091
Materials Science & Engineering: C (2018). DOI: 10.1016/j.msec.2018.03.002

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Whiskey webs: Where whiskey and science collide

ARTICLE AND DESIGN BY KELSEY MELCHER BURROUGHS, HEALTH SCIENCE, 2022

Looking for an unconventional career? Meet Stuart Williams, an associate professor of engineering at the University of Louisville who conducts research about whiskey. Williams is interested in the study of colloids, a type of mixture in which solid particles are suspended in fluid. He learned from a colleague that whiskey contains colloids, and that piqued his curiosity. Not long after, Williams began studying whiskey alongside Orlin Velev, a colloid science great, looking for an answer to the question: "Can you differentiate whiskey from their evaporated drops?" Williams and Velev discovered that when a diluted drop of the spirit evaporates, it leaves behind a beautiful matrix pattern, which they dubbed a "whiskey web."

Whiskey is a type of alcohol produced by distilling malted grain. Typically, whiskey is aged in charred oak wood barrels. American whiskey is aged in new charred oak wood barrels, resulting in an increased number of solid particles suspended in the alcohol. This contributes not only to the alcohol's flavor profile and color but also to its ability to dry in a whiskey web pattern.

The aging process that whiskeys, particularly American whiskeys, undergo plays a critical role in their ability to form whiskey webs. Williams found that drops of diluted American whiskey with an alcohol by volume of 30 percent or greater resulted in a uniform, thin film when evaporated. Drops of whiskey with an alcohol by volume of around 10 percent or less resulted in coffee-ring patterns when evaporated. In the middle range, whiskey webs formed.

So how exactly are these webs produced? Williams explains that, "when you dilute whiskey with water, some of its chemicals are water insoluble, thus creating micelles that would eventually migrate to the surface

[during evaporation]." This results in the formation of a chemical monolayer at the surface of the liquid. The surface area of this monolayer decreases in size during evaporation, causing a buckling phenomenon that creates web-like folds in the monolayer. These folds create the whiskey web pattern. Through his research, Williams showed that the chemical makeup of each whiskey affects the level of branching and wrinkling within its whiskey web, thus contributing to its unique pattern.

younger whiskeys to be marketed as expensive, higher quality whiskeys in order to trick consumers into paying more. Through the use of whiskey web image analysis, one is able to determine which whiskeys are authentic and which are counterfeit. This process may also aid in the chemical analysis of whiskey and play a role in quality control for whiskey distillers.

Another common pattern formed when liquid dries is called the coffee ring effect (CRE). This phenomenon occurs when a drop of colloid dries, leaving behind a stain in which the once-suspended particles dry on the perimeter of the drop. A common iteration of the CRE is seen with coffee stains, hence the name.

What occurred in Williams's research when he evaporated whiskey of alcohol by volume between 20–25 percent defies the expected CRE behavior. Thus, these findings may have implications for the suppression of the CRE in processes involving colloids, such as painting and inkjet printing. The CRE is often seen as an imperfection in paint and ink, and thus suppressing it results in superior products. The suppression of the CRE can also be used for the detection of nucleic acid for DNA sequencing as an alternative to polymerase chain reaction.



These intricate patterns can be visualized using digital imaging with a microscope or even with a smartphone. Through digital image analysis, Williams collected enough experimental data so that he was able to learn, recognize, and accurately match images of whiskey webs to the correct brand of whiskey 90 percent of the time.

Preliminary applications of Williams's findings include using whiskey fingerprints to identify knockoffs. It is not uncommon for lower quality

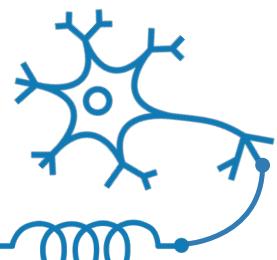
Looking at everyday spills and stains in a new light makes life's mundane routines all the more fascinating. It might even motivate some to prioritize washing their laundry. Perhaps there is more taking place in that blob of ketchup you spilled on your shirt than you might think! If you are interested in creating your own whiskey webs, Williams provides explicit instructions on his website: <http://whiskeywebs.org>.

ACS Nano (2020). DOI: 10.1021/acsnano.9b08984
Adv. Mater. Interfaces (2017). DOI: 10.1002/admi.201700944
Sensors and Actuators B: Chemical (2015). DOI: j.snb.2014.09.006

PHOTOS BY UNSPLASH

STORING MEMORY WITH LIGHT

How 50 years of research and innovation have brought us closer to efficient and dynamic information storage



BY CATRIN ZHARRY, BEHAVIORAL NEUROSCIENCE, 2023

What comes to mind when one thinks of physics and what comes to mind when one thinks of biology seem quite distinct. But over time, the two fields continue intersecting, especially as scientists try to replicate biological systems using electrical circuits. This is an enormous challenge because biologists first need to map and understand the original system, and physicists need to translate multilayered processes into a series of electrical impulses. However, a device made of metals called a memristor may be the key to efficient future biomimicry.

In 1971, Leon Chua, an electrical engineer at the University of California, Berkeley, published a paper called "The missing circuit element," in which he suggested that besides the resistor, capacitor, and inductor, there should be a fourth component to the basic passive circuit. He noticed that despite there being an equation and passive circuit element connecting almost every combination of circuit variables, there wasn't an equation nor element to relate charge and magnetic flux. Chua derived the missing equation to represent "memristance," but he didn't propose the possible physical qualities of a memristor. His paper was largely theoretical and served as an open-ended question to the rest of the physics community.

Thirty-seven years later in 2008, Stanley Williams, who completed his PhD in Physical Chemistry at UC Berkeley just seven years after Chua published his paper, answered the call in a paper titled "The missing memristor found." His team at Texas A&M University created a combination of metals that could change between two states depending on which direction current was passed through it.

The part that was most exciting to fellow scientists was that if you switched the metal to a particular state

and then turned off the circuit, the metal would "remember" which state it was in last when you turned it on again. Williams called one state ON and the other OFF because this is the binary system by which computers function: an ON (represented by 1) is an electrical impulse and an OFF (represented by 0) is the absence of it.

II The part that was most exciting to fellow scientists was that if you switched the metal to a particular state and then turned off the circuit, the metal would 'remember' which state it was in last when you turned it on again."

The combination of metals Williams built the memristor out of can be thought of as a sandwich with platinum as the bread and titanium dioxide (TiO_2) in between. Essential to Williams's memristor were two layers of TiO_2 side-by-side inside the "sandwich": one was normal and the other was oxygen-deficient. When a material is oxygen-deficient, some oxygen molecules are shot out of it, and the empty spots left behind are called oxygen vacancies. Positively-charged oxygen vacancies want to move toward a negative charge, and since currents are made up of negatively-charged electrons, the vacancies travel in the same direction as the electron flow.

If the current reaches the side with the oxygen-deficient TiO_2 first as it goes through the memristor, then the oxygen vacancies push into the regular

TiO_2 , following the flow of electrons. When they do this, they "convert" the section of normal TiO_2 into oxygen-deficient TiO_2 . If the current goes the other way, then the oxygen vacancies crowd together at the edge of the TiO_2 , leaving the majority of the TiO_2 oxygen-sufficient."

Changing how much of the total TiO_2 is occupied by oxygen vacancies is how the state of the memristor can be varied. The total resistance of the memristor depends on if most of the TiO_2 is oxygen-deficient or not. Normally, TiO_2 has high resistance to electric current because it is an insulator, but oxygen-deficient TiO_2 has low resistance. Williams called the low resistance state ON and the high resistance state OFF.

More recently, in January 2021, a group at the Institute of Materials Science of Barcelona created a memristor out of a modified combination of metals, but it holds memory by the same low-resistance/high-resistance principle. Incredibly, the unit they engineered can not only be switched between states by an electric current but by shining a light on it as well. Before this finding, memristors were exciting in the field of neuromorphic engineering, which aims to replicate nervous systems using circuits, but now they're even more promising because memristors could be activated with light in the same way sensory neurons fire in response to stimuli. Not only are memristors useful for biomimicry but they could also be incorporated into modern technology like cell phones and laptops because of their energy efficiency and compact size. Chua's ambitious proposal from 50 years ago that led to memristors may soon have a wide impact from carrying improved devices around in our pockets to making artificial brains.

Nature Communications (2021). DOI: 10.1038/s41467-020-20660-9

Nature (2008). DOI: 10.1038/nature06932

PHOTOS BY SHUTTERSTOCK

When flavors bloom:

What happens when we temper spices

BY AUDREY GALLIER,
COMPUTER SCIENCE, 2023
DESIGN BY KRISTI BUI,
COMPUTER SCIENCE, 2021

Some of the richest, most intense flavors are achieved by blooming, or tempering, spices. Integral to South Asian cuisine but applicable to many areas of cooking, the technique involves frying aromatic ingredients in fat before adding them to a dish. To understand how this works, we need to take a closer look at the chemistry of flavors.

Flavor comes from volatile flavor compounds, such as capsaicin in chili peppers or thymol in thyme. Volatile compounds are those that evaporate at relatively low temperatures. When we breathe, these airborne compounds enter through the nasal cavity and play a major role in

“Heat seeds, ground spices, herbs, or garlic in oil or butter over medium-high heat until they smell toasty and fragrant. Then use the mixture in recipes or drizzle it over cooked vegetables.”

how we perceive flavor. However, these compounds are sometimes prevented from evaporating when they are contained within whole seeds or locked in through drying processes. When applying heat to spices during the cooking

process, the compounds dislodge from the spices and more flavor molecules reach our sense organs.

Heat is crucial to releasing flavors, but there is another aspect to tempering: fat. Spices bloom best in fat as opposed to water. Most flavor compounds are fat-soluble instead of water-soluble, so oil can extract and absorb more of the molecules and help spread them throughout the dish. In a secondary effect, fat adheres to the tongue more strongly than water, bringing the flavor molecules into greater contact with our taste buds.

Since flavor compounds are chemically diverse, including alcohols, aldehydes, and esters, each ingredient may react differently to the process. For example, garlic becomes less intense when cooked because allicin, its main flavor compound, is destroyed by heat, whereas the flavor of thyme can become up to 10 times more intense.

Want to try this at home? Heat seeds, ground spices, herbs, or garlic in oil or butter over medium-high heat until they smell toasty and fragrant. Then use the mixture in recipes or drizzle it over cooked vegetables. You will be rewarded with magnificent flavors and a delicious-smelling kitchen!

Journal of the Science of Food & Agriculture (2020). DOI: 10.1002/jsfa.10341



BY MAYA KRAUSE, ENVIRONMENTAL SCIENCE, 2022

Most of the time, the natural phenomena that are visible from space are destructive forces such as hurricanes, volcanoes, and forest fires. But every so often, a beautiful display of flowers illuminates satellite images.

In the springs of 2017 and 2019, the dry hills in southern California exploded into what has become known as a “super bloom,” where thousands of flowers paint the hillsides with vibrant colors in a display that can be seen from space. These super blooms typically occur every 10 years on average and are prompted by winters with high rain and snowfall, leading to abnormally high volumes of wildflower seeds sprouting and blooming in the spring months. The native wildflowers that make their appearance in these displays include orange California poppies, yellow goldfields and desert dandelions, and purple delphinium and lupine.

These super bloom events have made tourist attractions out of some of California’s lesser-known protected lands. Parks such as Anza-Borrego Desert State Park and Carrizo Plain

National Monument have seen high spikes in visitors during super blooms. The small town of Lake Elsinore, southeast of Los Angeles, saw over 150,000 visitors over one weekend in March 2019 alone. The perception of these super bloom events as rare and iconic sparked the flood of visitors, who used the natural phenomenon as a backdrop for influencer Instagram posts. The super bloom events also help fuel the local economy as visitors to Anza-Borrego State Park account for over \$40 million in revenue to the region.

With the anticipated global temperatures on the rise, the reduced snowpack in California threatens the future of this colorful blossom display. As climate change begins to affect desert communities, they will be forced to adapt to the changing conditions of the parks they rely on for local economic support. For now, however, super blooms serve as a reminder that — amongst destruction — nature can also provide beauty.

Human Ecology (2020). DOI: 10.1007/s10745-020-00145-5

Buzzworthy behavior

Bumblebee nibbling promotes pollen production

BY SARA GANNON, BEHAVIORAL NEUROSCIENCE, 2021
DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Kindly thought of as the big, fluffy sibling of the well-respected honeybee, bumblebees spend most of their time minding their own business as they go about seasonal pollination. But recent findings show that these gentle giants may not be as lackadaisical as their reputation implies — they appear to be playing a very interactive role in their relationship with plants.

The bumblebee's role in pollination is symbiotic, meaning the plants benefit just as much as the bees do. The bees are helpful by inadvertently exchanging pollen between flowers, which facilitates plant reproduction, as they consume and transport pollen back to the hive. Pollen serves as an essential protein source for bumblebee workers and is the only food source provided to bee larvae as they grow. Because of this, the availability of flowers in the local ecosystem has crucial effects for bumblebee colonies and can greatly influence the success or failure of the colony from reproduction to social organization.

During springtime, synchronization of plant flowering and bumblebee colonization is vital for both organisms to achieve maximal benefits. With climate change occurring,

to the hive. This meant that bees may be compensating for pollen shortages by damaging the plant leaves such that flowering and pollen production are encouraged.

To first test whether or not leaf damage actually influences the plant's flowering schedule, the researchers set up a laboratory experiment. Using all of the same plant species, they compared the flowering schedules of plants with no leaf damage, bee-inflicted leaf damage, and damage done by researchers that was identical to bee-inflicted damage. They found that, overall, leaf damage led to earlier flowering regardless of how it was inflicted, but bee-inflicted damage had a much more dramatic effect on the flowering schedule. Human-inflicted damage led to flowering several days earlier than the non-damaged plants, but bee-inflicted damage advanced flowering by weeks. Human's lack of ability to recreate the phenomenon suggests there is a particular method bees use that scientists have yet to discover. It's possible that this difference is due to numerous mechanisms, from the technique of cutting, to the chemicals released, to the bees' detection of some salient quality within each leaf's anatomy.

Next, the researchers sought to uncover whether or not this behavior is influenced by the availability of pollen in the surrounding ecosystem. This experiment involved keeping two colonies in a controlled environment and limiting the amount of pollen available to each hive. In the first part of the study, one colony was presented with abundant pollen and one was deprived of pollen. The researchers then measured the proportion of leaves damaged each day, swapping new plants into the enclosure daily. After discovering a significant increase in leaf-damaging behavior in the pollen-deprived colony, they then continued on to the second part of the study. The team reversed the pollen availability in each colony and found the same compensating effect regardless of the colony's history with pollen availability. This showed that leaf-damaging behaviors increase under conditions of insufficient or limited pollen.

The discovery that bumblebees are capable of spurring flowering in plants and increasing pollen production is a wonderful new development in our knowledge of their behavioral repertoire. With climate change rapidly acting on local ecosystems and affecting annual plant and animal schedules, it is a light at the end of a dark tunnel to learn that some species have already developed the tools necessary to withstand and overcome these changes.

Science (2020). DOI: 10.1126/science.aay0496



II Bees may be compensating for pollen shortages by damaging the plant leaves."


environmental cues are shifting, and each year it becomes more difficult to achieve this seasonal synchronization. Recent studies explore the possibility that bumblebees themselves play a role in regional flower availability and are capable of influencing local plant populations' flowering schedules.

This behavioral phenomenon in bumblebees was recently elucidated by the Swiss Federal Institute of Technology in Zurich by Dr. Foteini Pashalidou and a team of researchers. The team investigated one bumblebee behavior in particular: the intentional damaging of leaves on flowerless plants.

Upon experimental observation of the leaf-damaging behavior, researchers concluded that bumblebee workers were cutting 5 to 10 distinctively shaped holes in the leaves of flowerless plants using their facial appendages, the proboscis and mandibles. Simple explanations for this behavior were considered, but it became clear that the bees were not consuming the leaf matter nor transporting it back

PHOTOS BY SHUTTERSTOCK

SPACE INVADERS: THE CARNAGE OF INVASIVE SPECIES

BY YAEL LISSACK, BIOENGINEERING, 2021

PHOTOS AND DESIGN BY IAN PROULX, BIOENGINEERING 2022

After a long day of exploring the lush jungles of Guam, you and your adventure buddies relax in the shade of a native coconut palm tree. Suddenly you hear a slight rustle of leaves in the canopy above. Fearing the worst, your eyes dart upwards in frantic search of the abundant, ill-famed brown tree snake that dwells in the tree canopy. Thankfully, you detect no snakes but spot small flecks of red that seem to float in the distance. Little do you know, you and your friends are about to witness one of the strangest conservation efforts of all time.

The brown tree snake (*Boiga irregularis*) was accidentally introduced to Guam by the U.S. military in the 1950s. The mildly venomous semi-constrictor snake was most likely brought to the island as a stowaway on a U.S. cargo shipment. Native to Australia, Papua New Guinea, and the Solomon Islands, the brown tree snake has had no natural predators in Guam and thus began prolifically reproducing shortly after its introduction. Since then, this invasive species has wreaked havoc on the economy and ecology of the island, driving 10 of 12 native bird species to extinction and outcompeting other predators for resources. According to the United States Geological Survey, the snake is also known to crawl on electrical lines and cause pernicious power outages. To control the spread, the USDA Wildlife Services came up with an unconventional plan. Though equivalent to a single child's dose of Tylenol, 80 milligrams of acetaminophen is enough to kill an adult brown tree snake. After they drugged dead mice as bait, conservationists attached the rodents to biodegradable parachutes and released them from planes above the jungle. The parachutes full of acetaminophen-laden mice landed in the trees where they were ingested by the arboreal snakes, killing many within as little as 24 hours.

Most of history is characterized by coevolution. Plants, animals, and microorganisms evolve alongside each other until they reach a delicate balance. Healthy ecosystems have limiting factors — variables within an environment that limit or control the range of other species (i.e., climate, predators, or food availability). Having evolved under a different set of limiting factors, a novel species can cause devastation in a new environment. Because these species often thrive in new environments because of their resilience, fending them off can seem like an unconquerable challenge.

The majority of invasive species are introduced by humans. The Kudzu vine, or “the vine that ate the south” was brought to the southern United States by European settlers for porch decoration and cattle feed. Kudzu has since become one of the most notorious invasive plants, killing native shrubs, groundcover, and even trees by outcompeting them for sunlight. In its native ecosystems of Japan and southeast China, the vine grows modestly, controlled by cold winters

and feeding insects. In the balmy climate of the South, however, Kudzu grows unchecked, transforming once biodiverse landscapes to a monolith of ivy-like towers.

Invasive species cost the global economy \$1.4 trillion each year, according to the Centre for Agriculture and Bioscience International (CABI). Though invasive species threaten ecosystems everywhere, the people who suffer most from their devastating effects are farmers and those who depend on the health and abundance of biodiverse natural resources to make a living. But this isn't just an agricultural problem, it's a major deterrent for community development. CABI estimates that approximately 70 percent of schoolchildren miss school during peak weeding times to manually remove invasive plant growth in agricultural fields. A team at the University of Tennessee indicates that invasive mammal species are responsible for 58 percent of bird, mammal, and reptile extinctions worldwide and categorize this problem as a “global conservation priority.” This wreaks havoc on those who rely on hunting native species for sustenance. Similarly, invasive water plants like the water hyacinth and species of the *Prosopis* genus can increase freshwater loss by up to threefold and deplete underwater oxygen levels, killing aquatic species that people rely on to survive.

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The people who suffer most from their devastating effects are farmers and those who depend on the health and abundance of biodiverse natural resources to make a living.”

This is a human problem; we cannot deny our dependence on natural resources and our role in their destruction. Unchecked, invasive species threaten our food and water sources, as well as the ecosystems we need and love. Ultimately, the best method of control is prevention, accountability, and awareness. There is one species, however, that threatens ecosystems more than any other. It has caused irreversible environmental damage and initiated mass extinctions of countless species — could humans be the most invasive species of them all?

Blooms of doom:

How toxic algae is harming marine life on the west coast

BY EVAN MULLANEY, PSYCHOLOGY, 2023

DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

It's no secret that climate change is responsible for a plethora of environmental issues, and according to recent research, a giant and toxic algal bloom off the west coast of the United States can be added to the long list of climate change-induced disasters.

According to a 2020 study published in *Frontiers in Climate* and conducted by researchers at the Northwest Fisheries Science Center, between 2013 and 2015, the Pacific Ocean underwent a series of extreme heatwaves, which were "five times more likely to occur due to anthropogenic forcing over natural variability alone." Harmful algal blooms (HABs) grow on the surface waters of warmer climates, so the warming of these coastal waters created a perfect environment for a HAB to thrive.

In 2015, these warm waters brought about a massive HAB caused by the diatom *Pseudo-nitzschia*.

HABs have appeared on the west coast in the past along areas like Monterey Bay and Heceta Bank, but unique weather patterns allowed the 2015 HAB to rapidly grow and spread. In addition to the heatwave, ocean storms caused an upwelling of nutrients from the ocean floor, feeding the algae and causing them to bloom at a faster rate than usual.

Data on ocean current trends between

2014 and 2016 show that algae from the HAB were carried unusually far north, but there were few currents to bring them back down, causing *Pseudo-nitzschia* to reside much further north than it typically does. During this time, a specific species of algae known as *Pseudo-nitzschia australis* began to grow. *P. australis* had previously been detected off the coast of California but was being found as far north as Washington. What differentiates *Pseudo-nitzschia australis* from *Pseudo-nitzschia*? The primary and most concerning difference is that it is even more deadly.

Pseudo-nitzschia and *Pseudo-nitzschia australis* are harmful to marine life because they produce a toxin known as domoic acid. The algae blooms on the ocean's surface yet has devastating consequences for life below. *Pseudo-nitzschia* forms chains that sink deep underwater where the algae is "seeded" into the sand, exposing species of deepwater fish, worms, Dungeness crabs, and razor clams to the toxic domoic acid. When this algae settles in sediment, it has the potential to aid future blooms if upwelling brings them back to the surface. Studies have shown that areas where *Pseudo-nitzschia* is seeded are more likely to spawn HABs

that become increasingly toxic each year because of this phenomenon.

The HAB growth in 2015 saw record cases of disease and death for marine life as the toxins worked their way throughout the food web. Species like seabirds may not have come into direct contact with the algae but were poisoned nonetheless as they consumed prey that had ingested domoic acid. In particular, poisoned shellfish brought about major problems for whale migration and fishermen. HABs delayed the start of the 2015 Dungeness crab harvesting season, resulting in a greater quantity of crab pots in the water during a later period than in previous years. Therefore, whales that were migrating during this time became entangled in the crab pot lines.

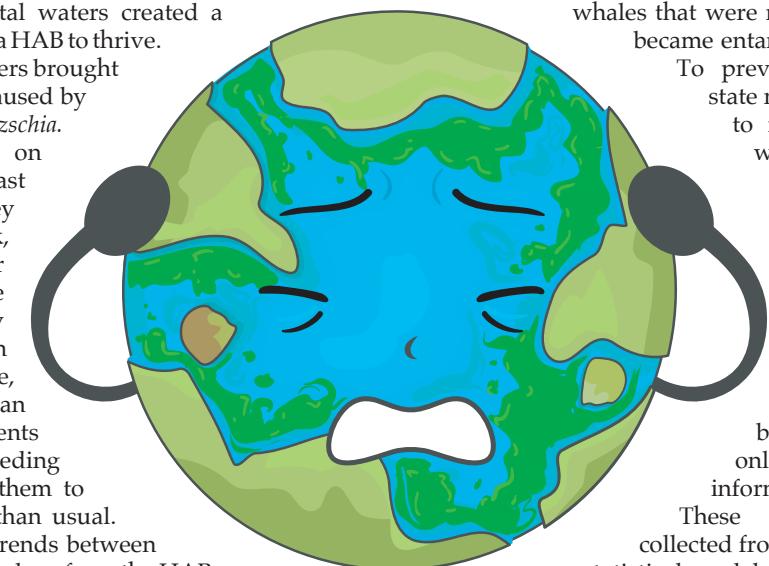
To prevent these entanglements, state measures were put in place to narrow the timeframe in which crabbers could set out crab pots, harshly limiting the size of their harvests.

If HABs occur annually and have such significant consequences, what can be done to foresee and work around them?

Multiple bulletins have been created and posted online to monitor and report information about HABs.

These bulletins display data collected from coastal waters as well as statistical models that estimate the impacts of HABs and their toxins. They are very helpful for fishing managers, especially those who fish for shellfish. By monitoring the bulletins, managers can know which areas are safe to fish in and when they should expect HAB growths to appear in prospective harvest areas. When these bulletins predict high levels of domoic acid and toxins in a specific region, managers can carefully monitor their shellfish and the toxicity levels of their catches.

Only time can tell how the HABs will progress in the future, and while environmental scientists are doing what they can to monitor these toxic blooms, there is no way to prevent them from happening entirely. At first glance, the massive 2015 HAB may seem like an isolated phenomenon, but it's unfortunately only a small reflection of a bigger environmental picture: If the climate crisis is not adequately addressed soon, the problems it causes now will only grow and poison the planet for years to come.





The American lawn

Is the grass always greener?

BY CARA PESCIOTTA, PHYSICS, 2022

DESIGN BY KAI GRAVEL-PUCILLO, PSYCHOLOGY, 2022

Lawns have long been the sign of a clean and respectable neighborhood, causing U.S. homeowners to maintain weekly or even daily upkeep on 40 million acres of lawn nationwide. The history and environmental impact of a trim yard, though, suggests the grass is not always greener with traditional lawns.

British colonizers initiated today's concept of a lawn by bringing grasses from Europe and Northern Africa across the Atlantic to replace nutrient-poor native grasses that could not sustain livestock. As foreign seed production grew, what began as a farming necessity turned into a residential luxury. European aesthetics influenced figures like George Washington to curate fields of manicured grass, and wealthy Americans were driven to emulate this symbol of status.

A 19th-century lawn was only tangible to those with the means to maintain it, requiring time for trimming and money for watering. Economic growth eventually allowed more homeowners to have yards, but this only exacerbated the grandiosity of lawns and perpetuated their close ties to high class and social status.

In 2017, households spent an average of \$503 on lawn care and gardening activities. This costly annual expenditure is indicative of the amount of resources lawn upkeep demands. Lawns in the United States require an excess of resources like water, fertilizer, and pesticides because they are composed of plants not native to the Americas. This excess of resources means lawns come at a hefty price not just for Americans but also for the environment.

Comparing lawn irrigation methods, NASA researcher Cristina Milesi estimates that "domestic and commercial consumptive water use would be [184 to 238 gallons] of water per person per day." For reference, medical professionals recommend just under one gallon of water per day for the average man — this means that 200 people could receive clean drinking water per person per day if water allocation for lawns was refocused. In places that suffer from water scarcity, like the western U.S., people have even begun to "drought shame" neighbors with suspiciously green lawns.

Excessive use of water on lawns is compounded by the impacts of mowers, fertilizers, and pesticides. The U.S. Environmental Protection Agency attributes 5 percent of air pollution, over 17 million gallons of spilled gasoline per

year, and equivalent emissions of 11 cars driven for one hour to lawn mowers. Each year the U.S. uses 90 million pounds of fertilizer and 78 million pounds of pesticides, both of which contain harsh chemicals that find their way into delicate ecosystems, the air, and drinking water.

To best combat the harmful nature of lawns, American homeowners will have to change their idea of what a luxurious yard is. While retaining a patch of low-cut lawn may be advantageous for homeowners with children, others can consider swapping out meticulously groomed carpets for native varieties of groundcovers and ornamental grasses, which can reduce or eliminate the need for unsustainable upkeep. Groundcovers, including thyme and oregano, provide a similar look to that of lawns in that they spread wide, do not grow tall, and discourage weeds. Ornamental grasses can serve as the leafy aspect of a lawn, creating features like clumps or bushes. Other options for a sustainable lawn include mosses, shrubs, and wildflowers.

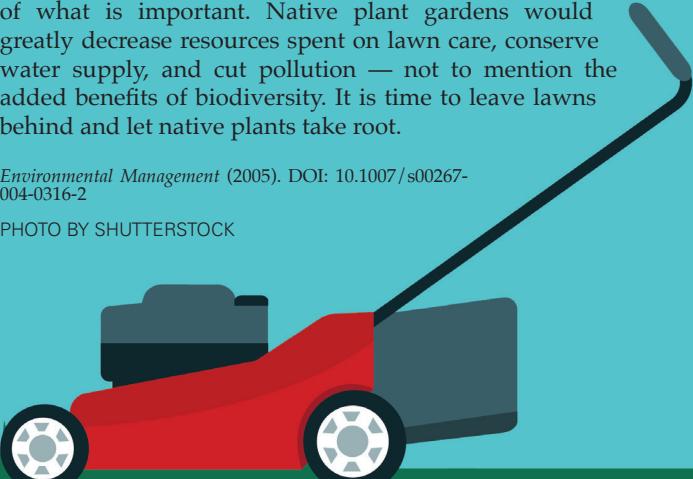
Choosing a native variety of these types of plants significantly decreases required maintenance. Unlike modern day lawns, native plants do not need to be watered, mowed, or fertilized because they are designed to thrive under the sun, climate, and precipitation conditions that they are growing in. This means reclaiming hundreds of thousands of gallons of water each year, eliminating a massive source of pollution, and increasing carbon capture since native plants produce longer roots.

Native plants also invite other welcomed advantages: wildlife. Increased plant diversity creates habitats for myriad insects and birds, allowing a vibrant ecosystem to form. Transitioning to native landscapes helps both the health of a yard and the environment as a whole.

Though lawns have long been a symbol of status and wealth, the suffering environment begs for a reevaluation of what is important. Native plant gardens would greatly decrease resources spent on lawn care, conserve water supply, and cut pollution — not to mention the added benefits of biodiversity. It is time to leave lawns behind and let native plants take root.

Environmental Management (2005). DOI: 10.1007/s00267-004-0316-2

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