New Scientist

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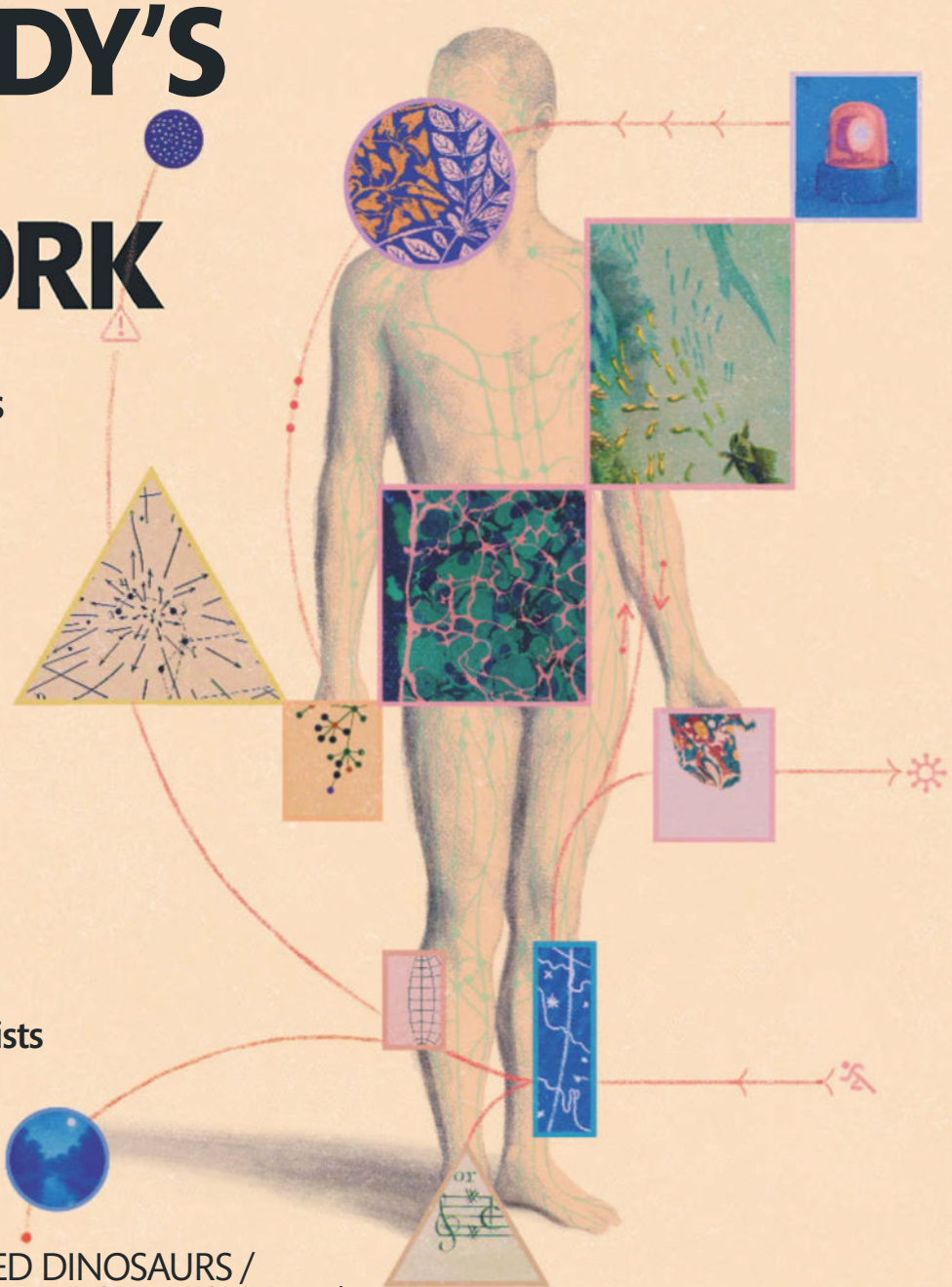
WHAT HAPPENS WHEN THE AI BUBBLE BURSTS?

BRAIN IMPLANT GIVES TELEPATHIC CONTROL OF ANOTHER PERSON'S BODY

HOW A GENETIC MISMATCH CURSED NEANDERTHAL-HUMAN HYBRIDS

THE BODY'S SECRET NETWORK

We're finally revealing the lymphatic system's extraordinary powers



EXCLUSIVE SPECIAL REPORT

Majority of climate scientists expect geoengineering this century

PLUS

ORIGINS OF LONG-NECKED DINOSAURS /
THE DEAD SATELLITE POLLUTION PROBLEM /
WHAT 350 THEORIES OF CONSCIOUSNESS REVEAL ABOUT REALITY

Science and technology news **www.newscientist.com**

Pure dodecadence?

The Twelve 660's profile is a minimalist 6.6mm. Accentuating its understated elegance is the absence of a date, second hand and luminescent paint. We re-engineered the bracelet. And re-sculpted the clasp, as the original would be taller than the new case. Yet the watch's distinctive DNA remains, in architectural elements like the dodecagon-sided bezel and lock ring. And glass-box sapphire crystals. The rear of which reveals the slim Sellita SW210 manual movement. Made slimmer still with a custom-designed, custom-made train bridge. In summary: same, different, less and more. Decadent design or perfected purity? You decide.

Do your research

Christopher Ward

christopherward.com

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Rules of engagement

Billionaires must not be given free rein to geoengineer the planet

Tackling climate change is an inherently collectivist endeavour. We only have one planet, with one atmosphere, and whenever anyone in the world emits greenhouse gases, we all feel the effects.

But some people have an outsized influence. Globally, the wealthiest 1 per cent are responsible for one-fifth of all emissions since 1990. If the richest people and nations voluntarily cut their carbon footprint, the entire world would benefit.

Of course, anyone with a passing grasp of reality knows this isn't going to happen. But what if the wealthiest instead try to fix their carbon imbalance by funding geoengineering efforts that aim to cool the planet back down? Here, the promise of global benefit is less certain. As we report in our exclusive survey of climate scientists (see page 6), the overwhelming risk of such an effort is that it could lead to unknown consequences, from causing drought to damaging the ozone layer.

Because of this, if we are to tinker with the planet's atmosphere in this way – and we may ultimately have to – it must only be done in a collectivist manner. And yet there is currently nothing stopping any individual or group from taking unilateral action to attempt planetary cooling. For that reason, more than 80 per cent of the researchers we surveyed say the world must agree an international treaty to govern potential deployment.

> "Globally, the wealthiest 1 per cent are responsible for one-fifth of all emissions"

Such a treaty would be one of many updates to global governance we need for the modern age. Another arena where billionaires have potential to impose their actions on the rest of us is the night sky, which is increasingly home to satellites that bring their own atmospheric harm (see page 32). With no global restrictions on launches, their number has shot up by thousands in recent years, mostly down to Elon Musk's Starlink programme.

International agreements aren't flashy or ripped from the pages of science fiction, making it much harder for them to attract billionaire backing. But if the wealthiest want to give something back, support for international law would be a good place to start. ▮

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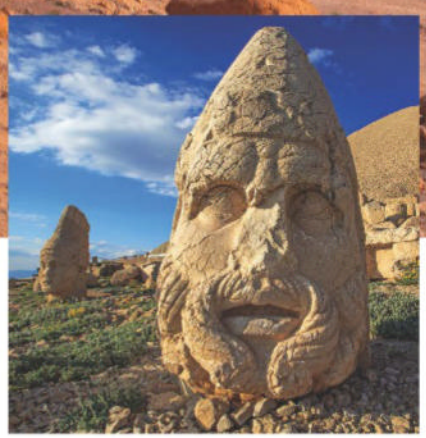

Human origins: Neolithic and Bronze Age Turkey

21 May and 9 September 2026
12 days

Embark on a captivating journey through Turkey, a land rich with historical treasures that illuminate the story of humanity's origins. Uncover the mysteries of these ancient landscapes guided by expert archaeologists, who bring the past to life in a vivid and memorable way.

- Visit 5 UNESCO World Heritage Sites, including Göbekli Tepe, Çatalhöyük, Goreme, Hattusa and Mount Nemrut
- Explore Neolithic and Bronze Age sites still under excavation

Dinosaur hunting in the Gobi desert: Mongolia

22 August 2026 | 15 days

Step into the lost world of the dinosaurs on an unforgettable expedition across the vast Gobi desert, one of the globe's most celebrated palaeontological landscapes. Join a small, expert-led team for hands-on fossil prospecting and excavation at some of Mongolia's most iconic sites.

- Venture to the iconic Flaming Cliffs, a dramatic landscape where the first dinosaur eggs were uncovered
- Accompanied by palaeontologist Dr Susannah Maidment

Machu Picchu and the science of the Inca: Peru

16 September 2026 | 11 days

Immerse yourself in the Inca civilisation, exploring the most important archaeological sites guided by renowned Inca specialist Dr Jean-Jacques Decoster. Discover Inca society, science and history while exploring the towns and landscapes of the beautiful Sacred Valley.

- Enjoy two visits to explore Machu Picchu
- Discover Inca cosmology and astronomical knowledge during a special stargazing evening

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News

JOSH DURY/SWNS

Astronomy

A once-in-a-millennium sight

This spectacular shot of a comet shooting across the night sky was captured from the Mendip Hills in Somerset, UK, by photographer Josh Dury. The object in question, Comet C/2025 A6 (Lemmon), was at its closest to Earth on 21 October. It should be visible from the northern hemisphere until early November, after which the comet isn't expected to be seen from our planet again for another 1000 years.

Climate change

Are we ready to dim the sun?

An exclusive *New Scientist* survey of climate scientists reveals concerns about schemes to tweak Earth's atmosphere to cool the planet, find **James Dinneen** and **Madeleine Cuff**

HUMANITY will attempt large-scale efforts to block radiation from the sun before the end of the century, according to leading climate scientists surveyed by *New Scientist*, in a last-ditch bid to shield Earth's inhabitants from the worsening impacts of climate change.

"The concept of solar geoengineering worries me greatly, but I can see it is becoming more attractive as the world fails to address the problem of reducing greenhouse gas emissions," says survey respondent James Renwick at the Victoria University of Wellington in New Zealand.

Two-thirds of respondents predict we will see risky interventions to tweak the atmosphere before 2100. Worryingly,

68%

of respondents think the use of solar geoengineering has become more likely, given failures to cut global greenhouse gas emissions

49%

support small-scale outdoor experiments to improve our understanding of the techniques

52 per cent say this will probably be driven by a "rogue actor" – such as a private company, billionaire or nation state – highlighting widespread concern that the world is moving closer to attempting such climate-cooling interventions without any global process in place to manage decision-making or mitigate the serious risks that deployment brings.

"The risks of unintended consequences, political misuse or abrupt termination remain huge," says survey respondent Inés Camilloni at the University of Buenos Aires in Argentina.

PA IMAGES/ALAMY

Solar geoengineering is proposed as one way to combat warmer temperatures

New Scientist invited nearly 800 researchers, all of whom have contributed to the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report on the state of climate knowledge, to participate in an anonymous online survey about solar geoengineering research, with some giving permission to be contacted afterwards. The 120 researchers who responded include experts from every continent specialising in a range of research disciplines across physical and social sciences. The results offer perhaps the most comprehensive view of the climate science community's views on solar geoengineering to date.

Scientists have been proposing ideas to tweak Earth's albedo – the amount of sunlight the planet reflects back into space – since the 1960s. The field has become known as solar geoengineering, or solar radiation modification (SRM).

Buying time

Cooling schemes would probably involve spraying particles into the upper atmosphere to reflect more sunlight away from the planet, a technique known as stratospheric aerosol injection. Another idea is to spray salt particles into low-lying ocean clouds, known as marine cloud brightening (see "Taming the sun's power", page 8).

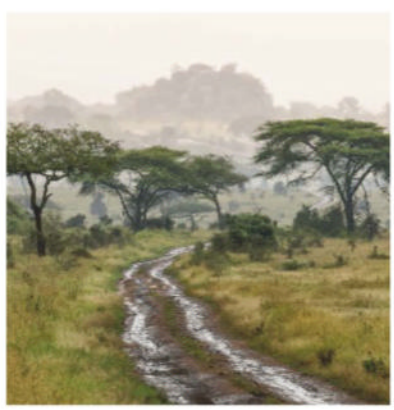
Some 68 per cent of respondents said the use of such measures has become more likely in light of failures to cut global greenhouse gas emissions over the past decade. "What I'm sensing is a greater awareness that we have not done what is necessary to properly tackle climate change," says Shaun Fitzgerald at the University of Cambridge's Centre for Climate Repair, commenting on the survey results. "What are our real options? We might not like them, but it's a case of not liking those and not liking the current trajectory that we're on."

But while there is some consensus that solar geoengineering will happen, experts were divided on what should trigger such drastic action. Just over 20 per cent of respondents said the world should seriously consider such measures if global temperatures become certain to exceed 2°C above pre-industrial levels, a scenario that looks increasingly likely as we blow past 1.5°C of warming. Others favoured waiting for more extreme levels of warming, while just over half said there is no level of warming at which we should seriously consider attempting to modify the atmosphere in this way.

Deployment could theoretically cool global temperatures and help buy time to slash emissions to avoid the worst impacts of climate change. But nearly all respondents pointed to huge risks of any large-scale deployment, ›

"The risks of unintended consequences, political misuse or abrupt termination remain huge"

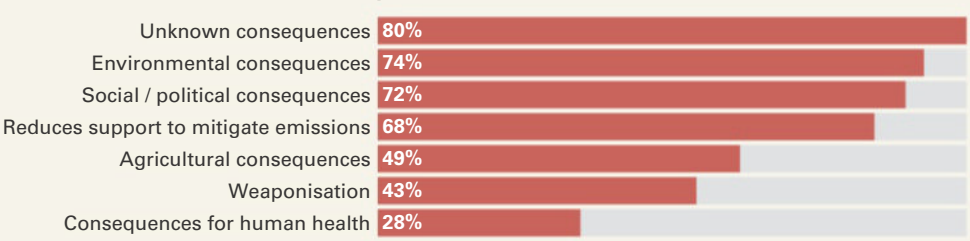
FADEL SENNA/AFP VIA GETTY IMAGES



DANITA DELIMONT/ALAMY

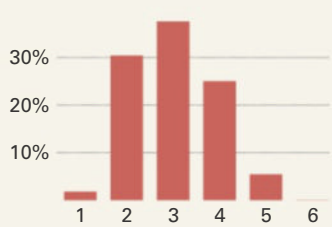
Enhancing cloud-cooling over the Indian Ocean may reverse drought in North Africa (top), but dry out East Africa (above)

Which of these represent the most serious risks of solar radiation modification (SRM), in your view?



SOURCE: NEW SCIENTIST

At what level of warming do you think SRM deployment should be seriously considered, if any? (°C above preindustrial average)



SOURCE: NEW SCIENTIST

including reducing motivation to cut emissions, disruption of rainfall patterns in vital agricultural regions and the sudden catastrophic warming that would result from "termination shock" if the interventions were to stop.

The survey also revealed palpable concern that countries or even individuals could decide unilaterally to press ahead with climate interventions despite misgivings from other nations. Some 81 per cent of respondents said the world needs a new international treaty or convention to govern all decisions over large-scale deployment, the greatest area of agreement across the survey.

These results "reflect a sensible position", says Andy Parker at the Degrees Initiative, a non-profit group that funds research on solar geoengineering. "This is a global technology. No one can opt out of a geoengineered world. By the same extension, no one can opt out of a warmed world where we've rejected geoengineering."

New Scientist decided to conduct this survey because, as climate impacts escalate, solar geoengineering research is becoming increasingly popular. Hundreds of millions of dollars in philanthropic and investor funding has flowed into the field, academics are presenting more work on the topic at scientific conferences and a global research community has started to emerge. Earlier this year, the UK government distributed £57 million in grant funding for solar geoengineering research via its Advanced Research and Invention Agency (ARIA), including support for small-scale outdoor experiments.

"Tinkering with the climate system at a planetary scale is a huge gamble"

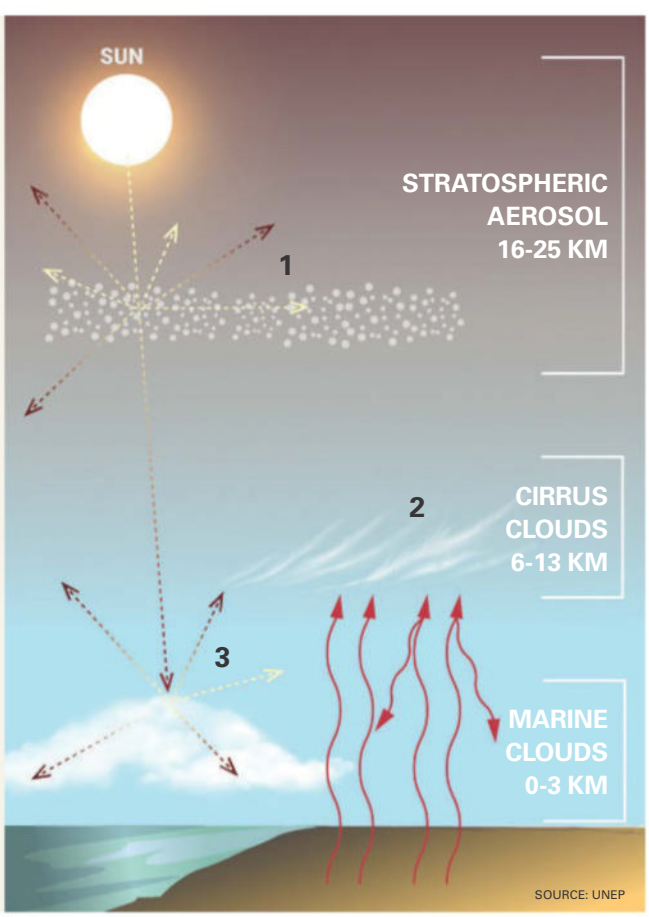
Taming the sun's power

There are three basic solar geoengineering methods

1. Stratospheric aerosol injection
This would involve releasing tiny particles of liquid called aerosols from planes high in the atmosphere, where they would reflect away sunlight. More than 60 per cent of survey respondents said this is the most likely method to be deployed.

2. Cirrus cloud thinning
Aerosols such as nitric acid could thin cirrus clouds, resulting in them allowing more heat to escape back into space. However, injecting too much aerosol could thicken the clouds and have the opposite effect. Only a small fraction of survey respondents thought this or land-based approaches to increasing Earth's albedo would be attempted.

3. Marine cloud brightening
Tiny droplets of seawater are sprayed into clouds, brightening them and increasing the sunlight they reflect. This was tested in a small field trial in 2024 aimed at protecting the Great Barrier Reef. Sixteen per cent of respondents thought this approach was the most likely to be used.



In the spotlight

It marks a big shift for a field that has long been at the fringe of climate science, says Daniele Visioni at Cornell University in New York, who leads a long-standing SRM modelling research group. "It has moved from a few academics vaguely talking about this to a global issue."

Just over one third of *New Scientist* survey respondents said they have become more supportive of research on SRM – though not necessarily deployment – given humanity's failure to cut emissions, while 49 per cent support small-scale outdoor experiments to improve understanding of the potential risks and benefits of any deployment.

"People are becoming more accepting of the need for SRM research," says Parker. "That links directly to pessimism to where we're going with climate change."

"Given that a majority of the experts surveyed see the use of solar radiation management in the coming century as likely, there is a critical need to collect robust real-world data on the feasibility and potential impacts of such earth cooling approaches," says Mark Symes, who leads ARIA's climate-cooling programme.

But support for geoengineering research is by no means universal. Some 45 per cent of survey respondents

SAN FRANCISCO CHRONICLE/YALONDA M. JAMES/EYEVINE

DANIEL GARRIDO/GETTY IMAGES

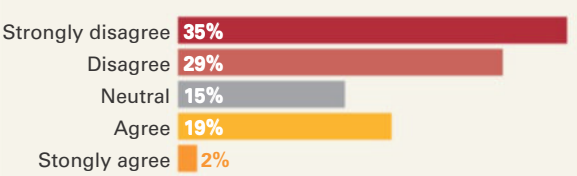
Does the world need a new international treaty or convention to govern potential deployment of solar radiation modification (SRM)?

SOURCE: NEW SCIENTIST

Do you anticipate countries or private groups will attempt to deploy large-scale SRM this century?

SOURCE: NEW SCIENTIST

Do you agree or disagree with this statement: "We should consider deploying SRM if the world's emissions trajectory means we are certain to breach the 2°C global average warming target under the Paris Agreement."



SOURCE: NEW SCIENTIST

Top: Injecting sea salt into marine clouds is one geoengineering method that has undergone small-scale tests

Bottom: Planes release aerosols into the air, which affect our climate

said it is a controversial or taboo field of research. One-third opposed outdoor trials of any measures, and 11 per cent said they had avoided contributing to solar geoengineering research in order to protect their professional reputation.

"To a lot of them [climate scientists], it signals the failure of what they always envisioned climate science to be for, which was to get the world to listen and reduce emissions," says Visioni.

The hesitation around solar geoengineering comes in part from the array of potentially catastrophic risks that could come from large-scale efforts to cool the planet by reflecting sunlight.

Nearly all survey respondents pointed to the possibility that deployment would dampen enthusiasm for emissions cuts as one of the most serious risks. Other threats include the risk of social and political instability, severe disruption to agriculture and food security, damage to fragile ecosystems and endangered public health. "Tinkering with the climate system at a planetary scale through SRM is a huge gamble," says Shreekant Gupta at the Centre for Social and Economic Progress in Delhi, India.

"Human intervention to repair damaged systems has a poor history of success"

For example, research has shown that enhancing cloud-cooling properties over the Indian Ocean could reverse drought in North Africa, but cause one in East Africa. Other studies suggest stratospheric aerosol injection could damage the ozone layer and cut monsoon rainfall in parts of Africa by up to 20 per cent.

However, the most commonly cited risk was simply "unknown consequences". "Human intervention to repair damaged systems has a poor history of success," one respondent noted.

Neuroscience

Feeling through another person's hand

A brain implant has helped a man with paralysis feel objects using someone else's hand – and might one day allow people to share experiences remotely, explains **Carissa Wong**

A MAN with paralysis has been able to move and sense another person's hand as if it were his own, thanks to a new kind of "telepathic" brain implant. "We created a mind-body connection between two different individuals," says Chad Bouton at the Feinstein Institutes for Medical Research in New York state.

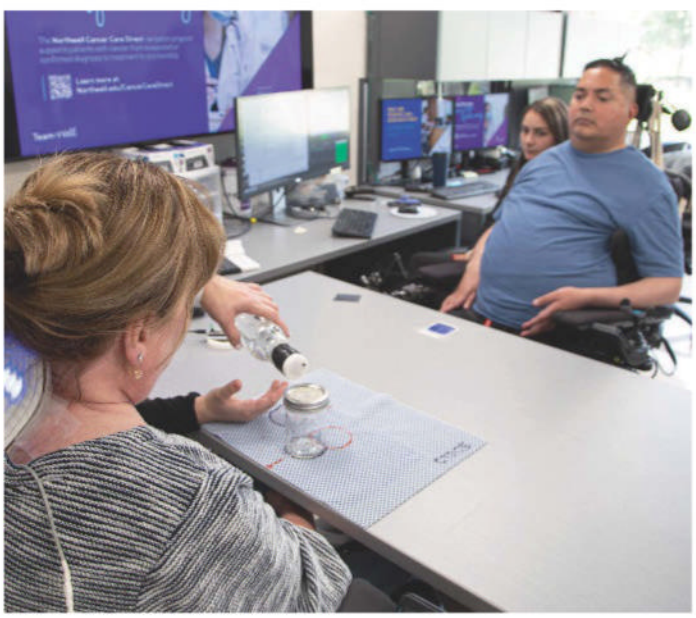
The approach could be used as a form of rehabilitation after spinal cord injury, allowing people with paralysis to work together, and may one day even allow people to share experiences remotely, he says.

Bouton and his colleagues worked with Keith Thomas, a man in his 40s who was paralysed from the chest down after a diving accident in July 2020, meaning he lost all sensation and movement in his hands.

In a prior study in 2023, the researchers implanted five sets of tiny electrodes in the parts of Thomas's brain involved in moving and feeling his right hand, allowing them to read his neural activity via a device fixed to his skull.

By feeding these signals into a computer running an artificial intelligence model, the team could decode the neural activity and wirelessly send signals to electrodes placed on the skin of Thomas's forearm, causing muscles to contract and relax to move his hand. Thomas also wore force sensors on his hand, which fed signals back into his brain implant via the computer to create a sense of touch. As a result, he could use his thoughts to pick up objects and feel them in his hand for the first time in years.

Now, the team has used a similar set-up to allow Thomas to control another person's hand and feel through it (medRxiv, doi.org/p9hb). In one experiment, the researchers asked a woman who wasn't disabled to wear the forearm electrodes and some force sensors on one thumb and index finger. While she made no attempt to move, Thomas was able to open and close her hand by imagining moving his own.



MATTHEW LIBASSI/FEINSTEIN INSTITUTES FOR MEDICAL RESEARCH

Keith Thomas (right) could control another person's hand by imagining moving his own

He was also able to feel, in his own hand, the sensation of her fingers closing around a baseball, a soft foam ball and a firmer ball – and, while blindfolded, distinguish between them based on their hardness. "It definitely feels strange," says Thomas. "Eventually, you get used to it."

> **"This technology could be a new way for humans to connect on a whole other level"**

He was only able to tell the balls apart with 64 per cent accuracy, but this figure could be improved by optimising the number and distribution of sensors worn on the hand, says Bouton. Thomas also wasn't able to feel the shape of the balls, but using more brain electrodes and force sensors would make this possible for various objects, says Bouton.

In another similar experiment, Thomas was able to help a woman with paralysis called Kathy Denapoli to pick up and drink from a can, something she struggled to do on her own due to having little movement in her fingers. "It actually was pretty amazing, you're helping somebody by just thinking about it," he says.

After working with Thomas for a few months, Denapoli's grip strength has nearly doubled, says Bouton. Because Denapoli's paralysis is less severe, it is hard to ethically justify her having the invasive surgery herself, and while similar improvements in grip strength can be achieved using standard therapies that electrically stimulate the muscles or spinal cord, Thomas and Denapoli found working together more engaging than rehabilitating on their own, says Bouton.

"There's benefit from just talking to them, like, 'How's your weekend?', and that makes you feel good about yourself and makes them feel good about themselves too," says Thomas. The team plans to trial the approach in more people next year, says Bouton.

Ethical concerns

Rob Tylor, who is paralysed and a lay member of the scientific committee at spinal cord injury charity the Inspire Foundation, sees value in this approach for some people with paralysis.

"It can be quite fun working with other patients, perhaps with similar experiences. It can very much contribute to someone's quality of life," he says. But appropriately pairing people with similar outlooks and motivations will be crucial, he adds.

Bouton acknowledges that many ethical questions surrounding who may benefit from the approach must be ironed out for it to gain approval for wider medical use, which he hopes to achieve within the next decade.

Hypothetically, such technology could even have non-medical uses, such as enabling people without disabilities to remotely control and feel through someone else, says Bouton. "This could be a new way for humans to connect on a whole other level."

But that raises more ethical issues. "Is it good or bad for society for people to be able to control and feel through other people?" says Harith Akram at University College London Hospitals. "You can imagine you could cause harm to another person through their own body, or commit a crime by controlling their body and say, 'It wasn't me'." ▮

Space

The centre of our galaxy may be teeming with dark matter particles

Leah Crane

STRANGE behaviour at the centre of our galaxy may be down to dark matter. In 2009, observations from the Fermi Gamma-ray Space Telescope revealed a surprisingly high concentration of gamma rays coming from the middle of the Milky Way, a phenomenon that has been dubbed the galactic centre gamma-ray excess (GCE). Now, simulations hint those gamma rays could come from the annihilation of dark matter particles.

The debate over what could cause the GCE has been raging since it was first spotted, with two main explanations emerging over the years. The first is it could come from an as-yet-unseen population of pulsars, which are rapidly rotating neutron stars that blast out beams of powerful radiation.

The second explanation is it could come from weakly interacting massive particles (WIMPs), which have long been the main candidate to comprise dark matter. These particles would barely interact with particles of regular matter at all, but if two of them happened to hit one another, they would annihilate and create a burst of gamma rays.

In recent years, the dark matter explanation has fallen out of favour, partially because direct searches for WIMPs have turned up nothing. "Considering the lack of direct evidence for the existence of dark matter, despite very sensitive searches, a higher burden of proof is demanded for the dark matter interpretation," says Jeff Grube at King's College London.

The other reason it has taken a back seat is because we would expect dark matter at the centre of the galaxy to take a spherical shape, and the GCE isn't spherical, but rather flattened in the middle. However, new simulations by Joseph Silk at Johns Hopkins University in Maryland and his colleagues indicate that might not be a problem after all.

These simulations took into account the history of the Milky Way in more detail than previous research into the GCE. "We know that billions of years ago, our galaxy suffered mergers with a number of smaller galaxies, and they brought with them their dark matter," says Silk. "A consequence of that history is that nobody in their right mind would expect the centre of the galaxy to be spherically symmetric."

"In some sense there's a 50 per cent chance we might have discovered dark matter in huge quantities"

The results bore that out, yielding a squashed distribution of dark matter that matched the shape of the GCE (*Physical Review Letters*, doi.org/p9pz). This puts the dark matter interpretation back on the table. But the mystery isn't solved yet – pulsars are still a viable explanation, too. "At best this leaves the situation ambiguous," says Grube.

The gamma ray observatories we have right now aren't powerful enough to distinguish between the two explanations, but we should be able to sort it out with the Cherenkov Telescope Array Observatory, which is expected to begin observations in 2026.

"In some sense, there's a 50 per cent chance we might have discovered dark matter in enormous quantities, but it's going to take a new telescope to sort this out," says Silk. If the GCE is due to dark matter, it will present the best opportunity we have ever had to understand this strange and enigmatic stuff that holds the cosmos together. ▮

Palaeontology

Fossil find rewrites how sauropods got their long necks

HIGH in the Argentinian Andes, a team of palaeontologists has found a small dinosaur fossil with the first hints of the extended neck that distinguishes sauropod dinosaurs like *Diplodocus*.

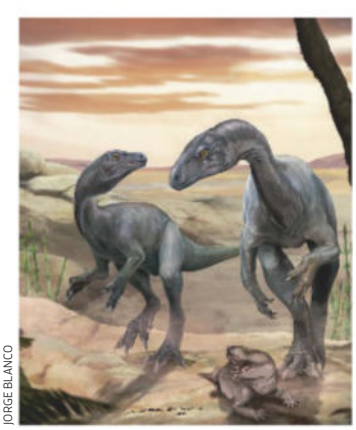
Named *Huayracursor jaguensis*, the fossil is a partial skeleton from a dinosaur that lived in the Triassic Period, around 230 million years ago. It was around 2 metres long and weighed about 18 kilograms.

Later, sauropods such as *Brontosaurus* and *Patagotitan* would become some of the largest and longest-necked animals ever to have lived, reaching lengths of over 35 metres and weights of more than 70 tonnes.

Until recently, it was thought that sauropodomorphs, the precursors of these long-necked herbivorous dinosaurs, were small, short-necked and possibly omnivorous.

Other sauropodomorphs living at the same time as *H. jaguensis* were much smaller, around a metre in length, and showed no signs of the lengthening of the neck bones seen in the newly found species. It wasn't until several million years later that sauropodomorphs began to significantly increase their body mass and lengthen their necks, palaeontologists thought.

The discovery of *H. jaguensis* at Santo Domingo Creek in north-west Argentina, by Martín Hechenleitner at Argentina's National Scientific and Technical Research Council and his colleagues, changes the story of how these dinosaurs got their long necks (*Nature*, doi.org/p9hd).



JORGE BLANCO

The Triassic dinosaur *Huayracursor jaguensis* was a precursor to sauropods

"*Huayracursor* breaks somewhat with this idea of a gradual transition, because it coexisted with its small, proportionally shorter-necked relatives," says Hechenleitner.

The dinosaur had a small skull compared with its contemporaries, robust hind limbs, slender hips and short arms with fairly large hands.

"*Huayracursor* drags the origin of the long neck and larger body size towards the first appearance of dinosaurs in the fossil record," says Hechenleitner. "It's fascinating to think that giant animals up to 40 metres long and over 30 tonnes, like *Argentinosaurus* and *Patagotitan*, are part of a lineage that began more than 100 million years earlier, with bipedal forms just over a metre long and a mere 10 to 15 kilograms [in weight]," he says. ▮

James Woodford

Ancient humans

Early hominin had the strength of a gorilla and a very firm handshake

James Woodford

A PAIR of hands belonging to an enigmatic ancient hominin that lived around 1.5 million years ago has been found for the first time, revealing that the species had gorilla-like strength alongside the dexterity to make tools.

Paranthropus boisei was first discovered by archaeologist Mary Leakey in 1959 at Olduvai Gorge, Tanzania. The skull was found alongside a type of stone tool known as Oldowan and it was claimed the species was the oldest known maker of stone tools. But because no hand fossils had been found, anthropologists couldn't be sure *P. boisei* had made them.

Now, Leakey's granddaughter Louise Leakey, a palaeontologist at Stony Brook University in New York, and her colleagues have reported the discovery of a partial skeleton of a *P. boisei* individual from a site near Lake Turkana, Kenya (*Nature*, doi.org/g964jf). It includes a pair of hands, a skull and some foot bones from an individual thought to be male.

Compared with earlier hominin species, this hand has more human-like proportions and straighter fingers, says team member Carrie Mongle. The hand is pretty "similar in size to my own, but much more robust", she says.

It has features similar to both modern humans and gorillas: for example, the thumb and finger bones are similarly proportioned to our hands, whereas other parts have much more robust bones, indicating the strength of a gorilla.

"Shaking hands with this individual would have been noticeably different than shaking hands with your average human," says Mongle. "They would have been much stronger."

It is now known that earlier hominins made tools, meaning *P. boisei* wasn't the earliest. But Mongle says there has always been hesitation to attribute Oldowan tools to *Paranthropus* because the remains of *Homo habilis*, a closer relative of modern humans, are often found in the same area.

"While we don't have any tools from this new site, the hand shows *Paranthropus boisei* could have formed precision grips similar to ours," she says.

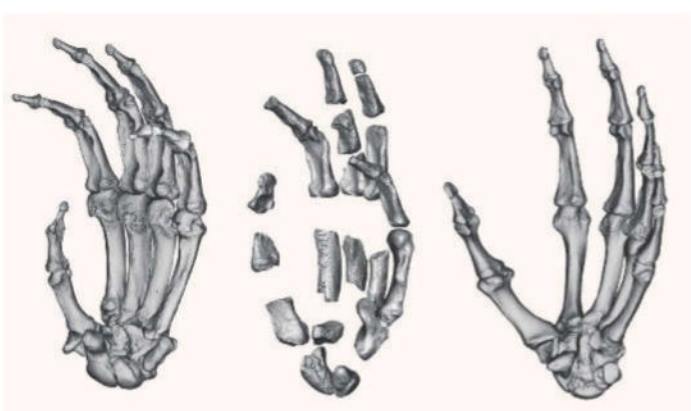
Julien Louys at Griffith University in Brisbane, Australia, says the find fills in some of the holes in our knowledge of the anatomy of ancient hominins, and *Paranthropus* in particular. He says the most surprising aspect wasn't the similarity to human hands, but the parts of the fossil that were similar to gorilla hands.

"Behaviourally, they must have had some parallels with gorillas, but obviously also retaining some of our own behaviours," says Louys.

"Getting a fairly complete hand of a hominin is incredibly rare. The evidence suggests that *Paranthropus* likely used tools, or at least had the right hardware to use tools, which isn't too unexpected," he says.

"I'm sure some people will continue to argue that only our own genus was capable of making more sophisticated lithics [stone tools], and short of finding a hand of *Paranthropus* clutching an Oldowan artefact, the debate will likely continue," says Louys.

The hand of a gorilla (left), *P. boisei* (middle) and a modern human (right)



TRACY KIVELL

Health

Artificial sweeteners may help your gut microbiome

USING low-calorie sweeteners in place of sugar seems to give beneficial gut microbes a boost and help people maintain weight loss. The finding, from one of the longest trials of sweeteners to date, indicates these products may not be as harmful as we thought.

Research has found low-calorie sweeteners may stoke hunger, increase blood sugar or raise the risk of heart attacks and strokes.

But long-term studies of sweeteners, especially in the context of a healthy diet, have been lacking. So Ellen Blaak at Maastricht University in the Netherlands tracked their effects in people who used them as a sugar substitute. She and her colleagues recruited 341 adults in Europe who were overweight or had obesity and placed them on a low-calorie diet for two months, leading to an average weight loss of 10 kilograms.

Afterwards, participants followed a healthy diet where less than 10 per cent of the calories came from sugar. During this weight maintenance period, 171 of the participants were told to avoid sweeteners altogether, while the rest were encouraged to use them. At least 16 varieties were used, and each individual could use as many types as they wanted.

After 10 months, those in the low-calorie sweetener group maintained a 1.6-kilogram larger weight loss, on average, than the sugar group. They also had a higher abundance of gut bacteria that produce short-chain fatty acids, beneficial compounds that research suggests help regulate blood sugar, support heart health and promote weight loss and maintenance (*Nature Metabolism*, doi.org/p9zd).

"Those using sweeteners had a higher abundance of gut bacteria that help regulate blood sugar"

"This shows that at least replacing sugars in the diet with non-caloric sweeteners may help you in maintaining body weight," says Blaak. Results may differ from previous studies because of its duration, and because it looked at sweeteners being used alongside an otherwise healthy diet, she says.

Grace Wade

The AI bubble is heading towards a burst, but it won't be the end of AI

Economists, bankers and even the boss of OpenAI are warning of a rapidly inflating AI bubble. If and when it pops, what will happen to the technological breakthroughs of the past few years, asks **Matthew Sparkes**

THE hundreds of billions of dollars being spent on AI seem to have inflated a global financial bubble that is now fit to burst, leaving companies and investors at risk of holding vast debt that cannot be serviced by the meagre revenue brought in by current AI services. But what does that mean for the future of the technology underpinning this financial feeding frenzy?

In recent weeks, warnings of a potential AI bubble have come from the International Monetary Fund, the Bank of England and even OpenAI boss Sam Altman. "This has not just been a stock market bubble, it's been an investment bubble, it's been a public policy bubble," says David Edgerton at King's College London.

The circular nature of some of the deals between major AI players is also raising eyebrows. For example, Nvidia, which builds the GPU chips that are powering the AI boom, recently invested up to $100 billion into OpenAI so that the company could build a new data centre full of Nvidia's own chips. OpenAI, in turn, has agreed a deal that could see it ultimately take a 10 per cent stake in Nvidia's rival chipmaker, AMD.

Red flags

Concern about the AI bubble bursting is also thrown into sharp relief when you realise the scale: at least $400 billion is being spent annually on data centres, according to Morgan Stanley Wealth Management. And while US GDP rose by 3.8 per cent in the second quarter of the year, Jason Furman at Harvard University estimates that if you removed data centres from the equation it would have barely grown 0.1 per cent over the whole first half of the year.

QILAI SHEN/BLOOMBERG VIA GETTY IMAGES

The true cost of AI tools may have been hidden from consumers

Carl-Benedikt Frey at the University of Oxford says this kind of exuberant deal-making isn't unusual in the history of technology – in fact, it would be unusual if the global economy managed to invest in infrastructure for a new technology at precisely the right pace to meet demand. "It's quite usual that you overbuild: the same thing happened with the railroad boom, the same thing happened with the dot-com bubble," he says.

The question is whether the fallout from an AI bubble would harm just the companies involved, or could have wider impacts. Frey points out that many of these hugely expensive data centres are actually being built "off balance sheet". This involves the creation of new companies, backed by external investors or banks that build and own the assets, taking on both the risks and potential rewards.

As a result, we don't know enough about who is exposed to this risk. A data centre could be financed by a dozen technology billionaires, or it could be high-street banks – and if their losses are large enough, then a banking crisis could send shockwaves throughout the wider economy. "That's not to say that there's an imminent financial crisis, but that it's a bit opaque. And when things are opaque, there's usually some risk," says Frey.

> **"At the minute, there's a lot of free lunch, but at some point these companies have got to make a profit"**

Benjamin Arold at the University of Cambridge says the giveaway is the ratio of profits to company valuations, which indicates how disconnected public opinion is from the actual money businesses bring in. He says these figures for technology firms today are a red flag.

"The last time it was this low was 25 years ago, and if you remember, 25 years ago we had the dot-com bubble," says Arold. "It's possible that it goes well, but I would not bet my money on it."

Course correction

James Poskett at the University of Warwick, UK, thinks we are heading for a correction in the AI industry that may spell the end for many companies, but he says this certainly isn't the end for the technology itself. "It's important not to confuse that with the idea that the technology is flawed or going to go away," says Poskett. "There might be an AI bust, but that doesn't mean we're not gonna have AI."

Just as the consolidation of numerous railway companies after a bust left us with a rail network, and the collapse of technology firms in the dot-com bust left us a legacy of extensive fibre-optic networks, we will be left with useful technology, says Poskett.

For consumers, the AI bubble popping is likely to mean a bit less choice, maybe paying a bit more for access and maybe seeing a slower pace of updates.

It could force us to face the reality that using a vastly expensive tool like GPT-5 to write an email is like using a sledgehammer to crack a nut, and that the true cost of using it had previously been hidden by the frenzied AI arms race. "At the minute, there's a lot of free lunch, but at some point these companies have got to make a profit," says Poskett. ▮

Genetics

Is this what killed the Neanderthals?

Neanderthal-human hybrids may have been scourged by a genetic mismatch

James Woodford

MODERN humans may indeed have wiped out Neanderthals – but not through war or murder alone. A new study suggests that when the two species interbred, a slow-acting genetic incompatibility increased the risk of pregnancy failure in hybrid mothers. A similar mismatch between mothers and fetuses may also help explain a subset of pregnancies that fail today.

We know from genetic studies that there was sustained interbreeding between *Homo sapiens* and Neanderthals between approximately 50,000 and 45,000 years ago. Neanderthals went extinct around 41,000 years ago, but some of their DNA has persisted in modern humans with non-African ancestry, making up around 1 to 2 per cent of the genome.

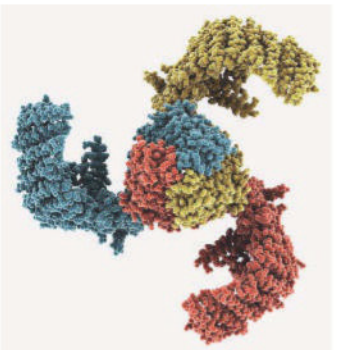
But mysteriously, none of the mitochondrial DNA in modern humans is derived from Neanderthals. This form of DNA is carried by egg cells but not sperm, so it is always inherited from the mother.

Patrick Eppenberger at the University of Zurich, Switzerland, and his colleagues have proposed a possible explanation for this. They suggest that women with

"Even a minor hit to reproduction can push small groups below the replacement rate"

Neanderthal and *H. sapiens* parents would have had a higher risk of pregnancy failure because of a mismatch between their genes and those of their fetus.

Neanderthals and *H. sapiens* had different versions of *PIEZO1*, a gene critical to oxygen transport in the blood. The researchers analysed modern human and Neanderthal DNA and modelled



Neanderthals and *Homo sapiens* have different versions of the PIEZO1 protein

the differences in the PIEZO1 protein to understand how the two variants would have interacted.

They also studied human red blood cells in the lab, using a chemical treatment to simulate the effect of the Neanderthal variant.

The team found that the Neanderthal variant, *V1*, results in red blood cells that bind oxygen more strongly compared with the *H. sapiens* variant, *V2*. *V1* is dominant, so a person who inherited both *V1* and *V2* would have red blood cells with this high oxygen affinity.

This means that a fetus resulting from a Neanderthal and *H. sapiens* interbreeding could have developed healthily in either a Neanderthal or *H. sapiens* mother. But according to the study, problems would have arisen in the next generation. A hybrid mother with *V1* and *V2* carrying a fetus with two copies of *V2* would have had higher oxygen affinity than her fetus, so she would deliver less oxygen across the placenta. This might impair the growth of the fetus and increase the risk of pregnancy loss (bioRxiv, doi.org/p9zb).

Eppenberger and his colleagues declined to be interviewed, but they argue

Neanderthal-human hybrid mothers may have had a higher risk of failed pregnancy

JOE MCNALLY/GETTY; ABOVE: LAGUNA DESIGN/SCIENCE PHOTO LIBRARY

that this incompatibility would have led to the Neanderthal population experiencing a drain on its reproductive output. Over millennia of coexistence, even low levels of gene flow from modern humans into Neanderthal populations could have introduced a gradual reproductive disadvantage, compounding over generations, they write.

One piece of the puzzle

It wouldn't be such a problem for the *H. sapiens* population because it was much larger, the team suggests. Neanderthal DNA could spread through the population via fathers, but the *V1* variant would quickly be eliminated by natural selection.

This could explain why Neanderthal nuclear DNA persisted in modern humans, while mitochondrial DNA, inherited only through mothers, didn't.

Although not derived from Neanderthal DNA, the researchers also note that some mutations in *PIEZO1* with a similar effect do occur today, and could cause some cases of unexplained pregnancy loss through a similar mismatch between mother and fetus.

Sally Wasef at the Queensland University of Technology in Brisbane, Australia, says the discovery of the delayed, second-generation incompatibility is a good insight. "Even a minor hit to reproduction can push small groups below replacement, which can start a slide in numbers and, in fragile settings, an extinction spiral," she says.

"That being said, I would treat this finding as one piece of the puzzle rather than the whole story," she says. "The effect is likely to be modest and to add to other ecological and social pressures."

Mental health

School phone bans may have surprising impact on socially vulnerable

Michael Marshall

MANY people are concerned about the negative consequences of too much screen time, particularly if phone use at school distracts students and affects their learning. But a study suggests banning them from schools makes some students lonelier, at least initially.

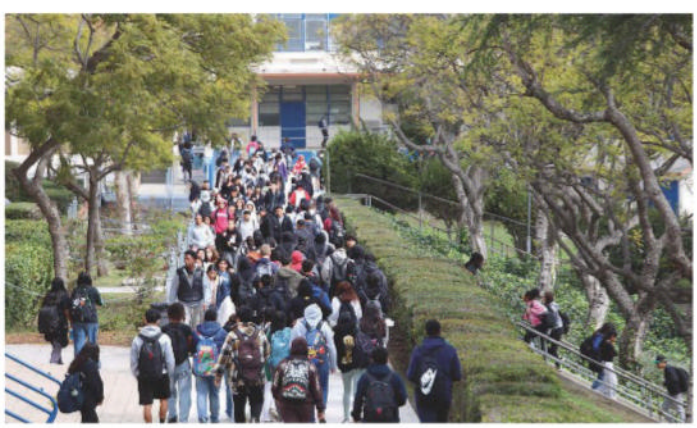
"If schools do decide to implement a total smartphone ban, there are some things that they should watch out for," says Sanyogita Khare at Radboud University in the Netherlands. "Socially vulnerable youth might struggle a little bit more. Students might feel a little bit more disconnected from their friends."

Mobile phones and similar devices have been blamed for a host of ills, from poor grades to declining adolescent mental health. Despite there being little robust evidence to support these outcomes, the Netherlands banned phones and other smart devices in classrooms from 1 January 2024. Some schools also prohibit students from using such devices at any time during the school day, often requiring they leave them in lockers.

To better understand the effects of this, Khare and her colleagues surveyed students from two secondary schools in the Netherlands, both of which have banned smartphones throughout the school day. The survey was first done in December 2023, before the nationwide ban, and again in March or April 2024.

From this, the researchers measured two forms of loneliness:

Schools have different policies when it comes to smartphone use



GENARO MOLINA/LOS ANGELES TIMES VIA GETTY IMAGES

social and emotional. "Social loneliness is more about the broader network – whether you feel part of a group," says Khare. "Emotional loneliness taps into more the feeling of closeness and intimacy in a close friendship."

When comparing how these changed from before to after the ban, the researchers found mixed results. "We didn't find an overall change in social loneliness, but we found a slight increase in emotional loneliness," says Khare. This might occur if some of the students' closest friends weren't in the school, so the ban prevented them from contacting those people during the day.

The team also found that, while the children's overall social loneliness didn't increase, those who struggled more with social situations tended to become more socially lonely (PsyArXiv, doi.org/p9hf). Khare emphasises that these outcomes might not be permanent if the students adjusted to the ban over time.

One issue with the study is that the researchers didn't compare these schools against other ones in the Netherlands that are more relaxed, for instance by allowing phone use at break time, says Jonathan Cantor at RAND, a non-profit research organisation in California. "We need data on similar students from similar schools without a ban to make meaningful comparisons. Without that, we can't determine whether the findings reflect broader trends."

Both Khare and Cantor say there is a lack of basic data about the effects of banning phones in schools. ▮

Solar system

A distant comet is forming new rings while we watch on

FOR the first time, astronomers are seeing a ring system form in real time. The rings in question encircle Chiron, a comet-like object that takes a path around the sun between the orbits of Saturn and Uranus.

Chiron isn't the first small object we have observed rings around: the asteroid Chariklo and dwarf planets Haumea and Quaoar also have small ring systems. All of these rings were spotted through a method called stellar occultation, which involves waiting for the object to pass in front of a distant star and then creating a map of how the star's light is blocked by orbiting material.

"There are only maybe 20 objects that have been observed through stellar occultations, so observing four of them with rings is high statistics," says Bruno Sicardy at the Paris Observatory in France. "There are hundreds or thousands of bodies out there, so there must be hundreds of ring systems." He expects we will find many more in the coming years.

Sicardy and his colleagues examined a stellar occultation that occurred in 2023 to nail down the structure of the rings around Chiron. While previous observations revealed the probable presence of three rings, this new observation showed an additional disc of material enveloping those rings and extending further from Chiron's surface, plus another ring even further out that has never been seen before (*The Astrophysical Journal Letters*, doi.org/p9zf).

"Nature is showing us a ring while it's in the formation stage, which is very lucky for us"

"Nature is showing us a ring in the formation stage, which is very lucky for us, because when we look at Saturn's rings or Uranus's rings, or even Chariklo's rings, they basically always stay the same," says Sicardy.

"[This could] shed light on the specific conditions that allow the formation, persistence or dissipation of rings, and may ultimately explain why such systems are only found in the cold, icy regions of the solar system," says team member Chrystian Pereira at the National Observatory of Brazil. ▮

Leah Crane


WATERLOO
SPARKLING WATER
WATER DOWN NOTHING
0 SUGAR
WATERLOO
SPARKLING WATER
GUAVA BERRY
0 CALORIES
SUGAR
SWEETENERS
SODIUM
NON GMO Project VERIFIED
nongmoproject.org
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CERTIFIED GLUTEN FREE
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Views

Comment

Do you like scary movies?

The prevailing wisdom is that horror fans lack empathy and are addicted to adrenaline. My research shows otherwise, says **Coltan Scrivner**

HORROR fans have been painted with the same broad and bloody brush for decades: labelled as cold, unfeeling thrill-seekers who delight in others' suffering. Film critics have described the fans and creators of films like *Friday the 13th* and *Saw* as "very sick people". Even among academics, the prevailing explanation for why some people love horror has been that they lack empathy or are simply addicted to adrenaline. In my new book, I argue that these assumptions are all wrong.

One of the most persistent misconceptions about horror fans is that they must lack empathy to enjoy watching films with so much suffering. This claim is intuitive and, until recently, was ostensibly supported by evidence presented in a meta-analysis from 2007. But a meta-analysis is only as strong as the studies it summarises. In this case, they had poorly defined variables. For example, the two studies with the strongest association with low empathy examined participant enjoyment of torture and short clips that concluded with brutal murders and no satisfactory resolution. These measures probably won't tell you much about horror fans, but they might tell you something about sadists. The authors of the meta-analysis admitted deep in the discussion section that the link between empathy and enjoyment of horror vanished when those studies were removed. Sadly, that caveat didn't make it into the abstract.

ADRIÀ VOLTÀ

In 2024, I published a set of studies that directly addressed the question of horror fandom and empathy. The results were striking. Using standardised assessments that measured empathy and compassion, I found no evidence that horror fans were lower on any measures of either. In fact, they scored higher on empathy and compassion on some measures.

Even with empathy out of the picture, the prevailing wisdom suggests that horror fans are just seeking an adrenaline rush. Some older studies even demonstrate evidence of this. However, the truth is more complex.

When my colleagues and I examined the motivations of horror fans at haunted attractions, we found that "adrenaline junkies" represent only one subset of horror enthusiasts. We also discovered a group we called the "white knucklers", who find horror genuinely frightening and dislike feeling afraid. Our research suggests that horror offers these fans a chance to overcome their fears and learn something about themselves. We also found a group we called "dark copers", who use horror as a way to process difficult emotions and experiences. They find a sense of catharsis in fictional fear. This three-type model reveals that many horror fans aren't just motivated by adrenaline. But there is one common trait among them.

My research has identified a personality trait called morbid curiosity as the most powerful predictor of horror fandom. It is this inclination to seek out information about dangerous, threatening or death-related phenomena that drives a fascination with horror media. And it may be good for you. Studies show that people with higher levels of morbid curiosity demonstrate better preparedness for real crises and show increased resilience during stressful life events. Horror fans, it seems, may be practising emotional regulation when they play with their fears through scary entertainment.

The evidence paints a picture of horror fans being empathetic, curious and psychologically sophisticated. Horror is a testament to human adaptability and our remarkable capacity to find meaning, connection and even growth in the face of our deepest fears. Recognising this not only helps us understand horror fans more accurately, but also illuminates something profound about human nature itself. ▮

Coltan Scrivner is author of *Morbidly Curious: A scientist explains why we can't look away*

Future Chronicles

The end of prison

By 2050, a self-monitoring system for criminals had replaced many prisons, leading to a drop in crime, predicts **Rowan Hooper** in his regular look at inventions yet to come

Rowan Hooper is *New Scientist*'s podcast editor and the author of *How to Spend a Trillion Dollars: The 10 global problems we can actually fix*. Follow him on Bluesky @rowhoop.bsky.social

In Future Chronicles, he explores an imagined history of inventions and developments yet to come.

This column appears monthly. Up next week: Chanda Prescod-Weinstein

IN THE 2020s, the US was spending an eye-watering $182 billion a year on locking up its citizens. No other country imprisoned as many people or spent as much in doing so. And the US wasn't alone: prisons in many countries around the world were overcrowded, inhumane and expensive. So why not just get rid of them? This became possible when technology was developed so that people could be monitored and detained at home – and when society caught up to the benefits.

The HomeGuard scheme, which replaced traditional prisons, comprised three elements. The first was an ankle bracelet that monitored the prisoner's precise location. The second was a harness containing sensors that recorded what the person was doing and saying. If the terms of the sentence were broken – for example, by the prisoner departing from the agreed area of confinement or engaging in illegal behaviour – the third element kicked in: the person was temporarily incapacitated by an energy device similar to a stun gun. Prisoners soon learned the rules.

It's no surprise that the first countries to abolish prisons were Scandinavian, where incarceration was viewed as a way to safeguard the rest of the community, rather than a means of enforcing punishment. ("HomeGuard" is a translation of the Norwegian word *hjemmevernet*.)

Halden Prison, a maximum-security facility in Norway, opened in 2010 with unbarred windows, ensuite bathrooms in cells, TVs and high-quality furniture. Inmates ate food and played games with unarmed prison officers, not guards, and were encouraged to work for money. Baffled outsiders compared the prison to a comfortable hotel. By contrast, in US facilities in the first quarter of the 21st century, prisoner abuse was widespread. Recidivism in Norway was around 20 per cent after two years, compared with 50 per cent in the UK and 60 to 70 per cent in the US. Halden was expensive, but prisoners were rehabilitated into society more effectively, which saved money in the long term.

Even in progressive Scandinavia, some members of the public felt that wrongdoers should be punished. However, sociologists found that if the public are shown that excessive, brutal and gratuitous punishment is bad for society and doesn't protect the community, they can be convinced that another method is better. This is what HomeGuard set out to do.

> **"AI monitored the actions of the prisoner, from the websites they visited to the messages and calls they made"**

The first *selvfengsel* ("self-prison") trial was launched in 2030 in Norway. Prisoners were fitted with secure ankle bracelets transmitting a GPS location signal, and a harness was worn that constantly filmed the face of the prisoner and ran it through face-recognition software. This prevented individuals from passing the sensor harness to another person. Artificial intelligence monitored the actions of the prisoner – for example, keeping check of what websites they visited and the messages and calls they made.

Action was taken if the terms of their sentence were violated. A conducted energy device is the hardware typically used in a stun gun. Integrated into a prisoner's ankle bracelet, it delivered an electric shock if the AI monitoring system determined a breach of sentencing rules had occurred. Law enforcement officers were then alerted.

The HomeGuard scheme was designed following a proposal in 2018 by Dan Hunter at King's College London and his colleagues. They calculated that even if prisoners were refitted with new tech each year, self-prison cost tens of thousands of dollars less than traditional prison over the course of a person's sentence. And the price came down further as the technology got cheaper.

Initially, *selvfengsel* was trialled in Bergen. All prisoners not convicted of capital offenses (or crimes of equivalent severity) were fitted with self-prison tech and sent home. The scheme was a huge success financially, which helped with the social message: brick-and-mortar prisons were expensive, inhumane, ineffective and archaic. For the rest of the world watching the trial, it became obvious that conventional prisons didn't adequately protect society because of high recidivism rates.

Technological incarceration was better all round, and *selvfengsel* soon spread across the rest of Scandinavia. Trials then took place across Europe and also in India, Mexico, Brazil, Australia and even the US. By 2050, 95 per cent of prisons in those countries had closed. The savings were invested in education and healthcare. Crime rates fell both because of the societal improvements and because the stigma of being constantly monitored was a powerful incentive to stay on the straight and narrow. Parents said to their children, "don't break the law or you'll go to self-prison," and the threat was sufficient. ▮

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1025NEW

Showstoppers

Photographer Alistair Veryard

THERE was a jam-packed programme of talks and exhibits on offer at this year's New Scientist Live at Excel London, which took place from 18 to 20 October and attracted thousands of visitors of all ages. With topics including the search for dark matter, how gaming has transformed technology, how animals treat themselves with medicine and the future of human reproduction, there was a huge range to explore.

Highlights included broadcaster and campaigner Chris Packham revealing the six species that have meant the most to his career, and GP Zoe Williams's talk about the hormonal fluctuations that take place over the course of a menstrual cycle, and how understanding these can empower girls and women.

After the talks, many people took the chance to meet with the speakers, from TikTok science star Big Manny to *This Is Going to Hurt* author and former doctor Adam Kay, and ask them questions while getting their books signed. Visitors also got to see the *New Scientist* podcast, *The World, the Universe and Us*, recorded live by Penny Sarchet and Rowan Hooper.

On the show floor, people could get hands-on with all kinds of exhibits (including giant insects, for those who dared). Visitors also explored a hospital of the future, showcasing surgical robots and augmented reality; took virtual rollercoaster rides; discovered how technology is transforming farming and more. For the first time, there were also workshops on everything from forensics to the science of whisky.

The talks were all recorded and will be available to stream online for 12 months. See live.newscientist.com for details of how to get access – and sign up for next year's show, taking place from 10 to 11 October 2026, with schools day on 12 October. An exclusive offer on tickets is running until the end of October.

Michael Le Page

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1. Zoologists and TV presenters Chris Packham (left) and Megan McCubbin (right) tell Gina Rippon, author of *The Lost Girls of Autism*, how their neurodivergent brains have powered their careers
2. Getting to grips with a plasma globe at the UK Atomic Energy Authority stand
3. Medic Zoe Williams reveals how women and girls can hack their hormones
4. Experiencing the joys of flight with the Royal Air Force
5. Building a molecule at the Middlesex University stand ›


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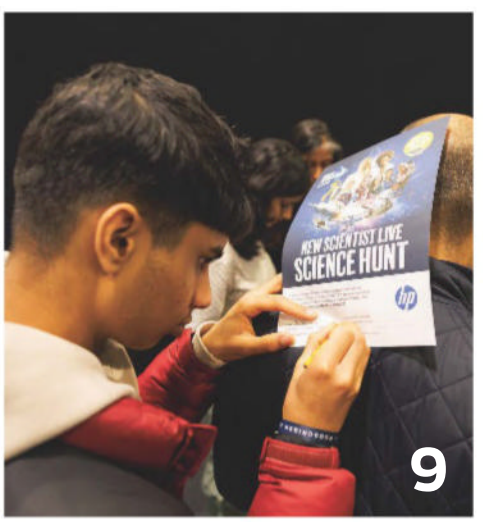
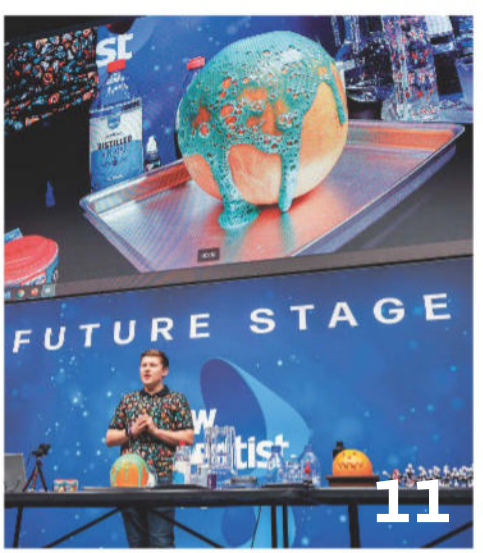


6. Historian of science Michael Wright delves into the mysteries of the 2000-year-old Antikythera mechanism with author Jo Marchant
7. Edinburgh Napier University gets into the Halloween spirit
8. A packed audience for TikTok star and author Big Manny, with a large model of the moon, courtesy of the National Space Centre, in the background
9. Engrossed by the New Scientist Live Science Hunt
10. A rapt audience watches Big Manny's talk
11. Chemical biologist and *Great British Bake Off* finalist Josh Smalley delights with the "spooktacular science of baking"
12. Geologist and science communicator Chris Jackson asks whether geology can save the world
13. Visitors explore how to feed the planet sustainably at the future of food and agriculture stand
14 Quantum physicist Maria Violaris predicts how quantum computing could change our lives



Power of pragmatism

In the run-up to this year's COP summit, **Madeleine Cuff** explores an excellent and poignant account by a negotiator who showed what diplomacy can achieve

Book
The Climate Diplomat
Peter Betts
Profile Editions

IISD/ENB LEILA MEAD

Peter Betts (seated, pink shirt) at COP17 in Durban, South Africa, in 2011

CLIMATE negotiators, lobbyists and world leaders will descend on the Brazilian rainforest city of Belém next month for this year's UN climate summit, COP30.

For anyone who has been to a COP summit, or tried to follow one from afar, the meetings can feel completely bewildering. Dozens of parallel negotiating tracks take place at the same time, replete with cryptic agendas and buzzword-y labels, ranging from "dialogues" and "consultations" to "informal informal" discussions.

To an observer, it can feel like a vast talking shop, wrapped up in its own conventions and with little relevance to the outside world. Thankfully, we have the wisdom of Peter Betts, a legendary figure in COP circles, to set us straight.

Outsiders are unlikely to have heard of Betts. But as the former lead climate negotiator for the UK and the EU, he played a central role in laying the groundwork for the Paris Agreement and in steering negotiations that got it over the line in 2015.

Betts sadly died of a brain tumour in October 2023, and his book, *The Climate Diplomat: A personal history of the COP conferences*, was published posthumously this August. It offers an insider's account of what goes on at climate summits and takes us through their modern history, beginning when Betts took charge of UK international climate policy in 1998.

The first thing to become clear is that, although COPs are often held in far-flung locations, from Peru to Paris, Durban to Dubai, the life of a climate negotiator is hardly glamorous. National teams spend years strategising and planning their negotiating tactics for the annual two-week summits, only to spend the entire fortnight locked in windowless temporary buildings as they thrash out the fine details.

"Amid the chaos, negotiators must find a way to bring everyone to the table and reach consensus"

At COP17 in Durban, South Africa, Betts recalls how delegation offices were sited underground in a car park that "reeked of petrol and diesel fumes", while at COP15 in Copenhagen, Denmark, the food "consisted almost exclusively of large circular rolls filled with a brown paste". Clearly, climate diplomats aren't in it for the jet-setting lifestyle; they truly believe this is the best way to solve the climate crisis.

Slowly, over the course of the book, it becomes clear why, as Betts takes us on a crash course on how a COP summit works, including the rules governing meetings and the negotiating positions and objectives of different countries.

The sheer range of issues is mind-boggling: some nations focus on securing more financial aid for development, others want nations to step up and commit to ambitious cuts to greenhouse gas emissions, while some are simply there to obstruct progress and maintain the status quo. Each country is also hamstrung by its own domestic politics, financial position and cultural outlook.

Amid the chaos, negotiators must find a way to bring everyone to the table and reach consensus – unanimous, no less – on the next steps to solve climate change. To call this a tall order is indeed a colossal understatement.

Betts writes with clarity and an often acerbic wit, even if there are some dense sections on, say, the intricacies of multilateral climate finance. But, gradually, you start to understand how the COP sausage is made, and how the strands align to build a finely balanced agenda in the hope of bringing nations together under a common goal.

Where things really come alive is when we are taken behind the scenes of the major summits – Copenhagen, Paris, Glasgow – and given the inside track on how things unfolded. We hear of prime ministers and presidents "robotically eating biscuits" in crunch meetings, stealing the show with unplanned, "damaging" press conferences, hiding in the VIP areas from their teams and "exploding" with anger when things don't go their way.

There's also more than enough gossip about Whitehall movers and shakers to keep British politicos engaged, and some perceptive insights into how climate campaigners have fallen short – and sometimes even damaged progress on emissions reduction – with their lobbying strategies.

There are plenty of people who dismiss the role of these summits in driving global climate action, arguing that they are little more than a tortuous gab fest. But the evidence shows otherwise: before the Paris Agreement was struck in 2015, the world was on course for 5°C of warming by the end of the century. A decade later, that trajectory has fallen to about 2.7°C – still far too high, but a long way from the truly catastrophic fate we were headed towards.

Diplomacy can change the world. In this book, Betts provides an unparalleled insight into exactly how this change can happen.

Staying alive – for now

Why does it matter that rich tech bros are out to cheat death? **Graham Lawton** finds out in a brilliantly troubling new book

Book

The Immortalists

Aleks Krotoski

Bodley Head, UK, out now; US, April 2026

IN ALL my years covering ageing research, I have paid little attention to the fringes, at which people (mostly rich white men) strive to cheat death, or at least add decades to life. Thankfully, journalist and social scientist Aleks Krotoski has, and her portrayal of "the immortalists", as she calls them, is eye-opening, entertaining and disturbing.

The quest for eternal life is as old as humans, of course, but recently it has taken on a new, sinister twist. In the driving seat are Silicon Valley "tech bros", who see ageing and death as just another problem to solve. They have what Krotoski calls "engineer's syndrome" – a hubristic belief that any complex problem can be cracked using engineering thinking, even in fields (usually biological) about which they know nothing.

That is certainly true of the egotists who fill *The Immortalists: The death of death and the race for eternal life*. Most of the movers and shakers in Krotoski's book have a background in computer science or engineering, and are steeped in the "move fast and break things" Valley ethos. When they do pontificate about the causes and possible solutions for ageing, they generally display a profound ignorance. They are wedded to the increasingly rickety idea that ageing is the result of accumulated damage, for example. Many biogerontologists see this as yesterday's paradigm.

They are also not that interested in what actual scientists have to say. There is an extremely illuminating passage about halfway in, where Krotoski reports from RAADfest 2022, the annual gathering of an organisation called the Revolution Against Ageing and Death.

Most of the speakers come from the biotech and the wellness industries, but one, Irna Conboy, is a bona fide research scientist. Along with her husband Mike Conboy, she studies regenerative medicine at the University of California, Berkeley. Some years ago, the Conboys discovered that transfusing plasma from a young mouse into an older one (a procedure called plasmapheresis) has a rejuvenating effect. This, unsurprisingly, caused a bit of a stir in the radical life extension community, but Conboy sought to dampen down the hype.

Krotoski describes Conboy's presentation, delivered via Zoom and titled "Old Plasma Dilution Reduces Human Biological Age: A clinical study". It sounds like a standard paper at a scientific conference, with data, technical language and the careful conclusion that the procedure may one day reduce biological age.

But at this gathering, there's no room for equivocation: the presentation goes down like a lead balloon. What the audience wants is plasmapheresis, now. Despite being told in no uncertain terms that it is "extremely unsafe", RAAD co-founder James Strole wraps up the presentation by saying, "I can't wait to get in there and get some plasmapheresis." You will meet many similar characters in this highly readable and meticulously researched book.

You might think this is a bit of a lark, but Krotoski also documents the growing political power of the immortalists, who she says include some of the world's richest and most influential people, including Elon Musk, Jeff Bezos, Sam Altman and Peter Thiel. All have varying ties to Donald Trump's White House and, according to Krotoski, are behind moves to cut funding for research designed to help today's older people in order to advance their own techno-utopian vision.

In this respect, the life extension and immortality agenda is less important than their wider goal: radically rewiring the US government in the image of Silicon Valley.

On whether all of this is a good thing, Krotoski is a stoic agnostic. Her goal is to open people's eyes to what is going on so they can make up their own minds. She does it brilliantly.

Some rich and powerful tech bros want to recast the US government in the image of Silicon Valley

STEVE PROEHL/GETTY IMAGES

New Scientist *recommends*

Obomate Briggs
Video producer
London

As a lover of fashion, I was intrigued to visit **Material World**, the first festival at London's Royal Botanic Gardens, Kew, devoted to fashion and textiles. Staged in the Temperate House until 2 November,

the exhibition sees artists, designers and scientists explore plants, textiles and sustainability.

One standout is Nnenna Okore's *Between Earth and Sky*. Hanging 20 metres above the ground, this large-scale sculptural work turns simple materials into intricate, immersive forms, while the use of biodegradable materials, responsibly sourced fibres and natural dyes encourages us to ponder our own responsibilities.

The focus on organic materials continues in the Growing the Next Era of Fashion section, with clothes made from plants and fungi. I especially loved a dress knitted from pineapple fibre and nettle leaves (pictured).

My big takeaway was that sustainability in fashion is as much a creative opportunity as a technical challenge, and that all our choices reveal how we relate to nature.

INES STUART-DAVIDSON/RBG KEW

The road not taken

A distressing documentary shows how George H. W. Bush might have helped avert climate disaster. It is a vital wake-up call, says **Bethan Ackerley**

Film

The White House Effect

Directed by Bonni Cohen, Pedro Kos and Jon Shenk

Streaming on Netflix from 31 October

NETFLIX

President George H. W. Bush, left, with his pro-green advisor Bill Reilly

THE opening sequence of *The White House Effect*, a harrowing new climate documentary, transports you to the great drought of 1988. Picture the scene: a sweltering summer across North America brings the worst drought to the US since the Dust Bowl of the 1930s. There is no respite. The heat is inescapable.

These extreme conditions set the agenda for that year's presidential race between Democrat Michael Dukakis and Republican George H. W. Bush. The latter would win in a landslide with a platform promising greater environmental protections.

"Some say these problems are too big," Bush said on the campaign trail in Michigan, in reference to climate change. "My response is simple: it can be done and we must do it. These problems know no ideology, no political boundaries." Such a statement from a leading Republican politician seems beyond unthinkable today.

Not only is the US of 1988 a place where green interventions are a vote-winner, it is one where the relationship between fossil fuels and rising temperatures is reported relatively stoically, albeit with plenty of scepticism.

Told largely through archival footage, *The White House Effect* is an ersatz glimpse at a better future that never materialised. It is the story of how millions of people were poised to accept that tackling climate change is a bipartisan concern – and how they were encouraged to abandon that view.

The key battle at the heart of the film is between two of Bush's advisors. In the blue corner, we have Bill Reilly, a former president of the World Wildlife Fund, who became the head of the US Environmental Protection Agency in 1989. In the red corner, we have John H. Sununu, Bush's chief of staff and an inveterate climate sceptic. The twin forces guiding the Bush administration's environmental policies would duke it out for years, with catastrophic results for our planet.

"In reference to climate change, George H. W. Bush said the problem knows no political boundaries"

Looking at the world around us, it should be no surprise which side won out, of course. But the compelling thing about *The White House Effect* isn't its foregone conclusion; it's the specifics of this slow march towards doom. The documentary's archival footage is always riveting, particularly in combination with its frequent jaunts backwards and forwards in time, which help underline the film's argument. It keeps the viewer on their toes, lest the sheer bleakness of what they are seeing dull their acuity.

We visit the 1979 energy crisis, for example, in which millions waited for hours to refuel their cars amid a drop in oil production, while oil giant Exxon's third-quarter profits soared by 119 per cent. One motorist waiting at a gas station remarks that everyone really ought to head home and wait out the shortage. Asked why he isn't turning back, he replies: "I'm not doing it because nobody else is."

There are many climate scientists featured in the documentary, but none so prominently as Stephen Schneider, who was among the first to stick his head above the parapet and try to force action on climate change. He serves as an emotional throughline for the film, from his first appearance, in which he testifies before a US Senate committee in 1988, to his last, filmed shortly before his death in 2010.

"If I go all the way back to when I really started pushing this issue, most of my immediate objectives have failed. But here we are. We have haltingly made progress," he says. "People have learned the problem [of global warming] so well now that we're on the edge of actually implementing cultural change, but that moves at [a] generational timeframe."

It is heartbreaking to imagine how Schneider would view the past 15 years of squandered efforts, not to mention the direction the US is heading in under its current president.

Watching *The White House Effect* is a smothering experience. It will leave you embittered, particularly if you, like me, were born too late to have witnessed its events first-hand. And if the film is a polemic, it's a necessary one, designed to shake us from apathy and stagnation by any means possible – or necessary.

Editor's pick

Going down a black (rabbit) hole

4 October, p 28

From Rachael Padman, Cambridge, UK

In his article "What's inside a black hole?", Stuart Clark is troubled at the thought of conceding that "the universe is not entirely ruled by physics".

As a physicist, I am content to think that the universe is *always* ruled by physics, and in fact that is a tautologous statement. But I am happy – in fact quite excited – by the thought that we don't yet know some of that physics. How desperately sad it would be if the only thing left to do was to apply our existing theories to yet more systems.

The universe doesn't need our theories or our permission to do what it does. I sometimes wonder whether some of my colleagues haven't themselves gone down a black rabbit hole in their failure to accept that.

From Don Taylor
Cheadle, Staffordshire, UK

Stuart Clark doesn't mention Carlo Rovelli's idea that singularities can exist only in the future. In his book *White Holes*, he says that because time slows down in a strong gravitational field, a point of infinite density with infinitely strong gravity would take an infinite amount of time to form.

So, from our point of view outside the black hole, what we are seeing is a potential singularity, but the collapse to a single point will take forever, and perhaps the physics won't break down within the lifetime of the universe. This makes a lot of sense to me – what am I missing?

From Richard Grimmer,
Trowbridge, Wiltshire, UK

Are gravastars, electroweak stars, boson stars and fuzzballs really needed to do away with singularities?

From our perspective, standing beyond the black hole, gravitational time dilation means that anything that falls into it slows down as it approaches the event horizon and takes an infinite amount of time to actually reach it. So, from the exterior point of view, the material falling into a black hole never crosses the event horizon.

Meanwhile, black holes are believed to emit Hawking radiation and "evaporate" over a very long, but nonetheless finite, time. If matter takes infinite time to enter, but finite time to leave a black hole, then the singularity never forms.

From Philip Le Riche
Harpenden, Hertfordshire, UK

I always understood that time grinds to a halt at a black hole's event horizon. If so, it is surely nonsensical to ask what is inside a black hole, and by implication, whether at this moment it contains a singularity.

So if I were to fly my spaceship across the event horizon of a black hole, I'd see the entire future of the universe play out in my wing mirrors before (if ever) hitting a singularity!

Why AI is right only some of the time

27 September, p 15

From Crispin Piney
Mougins, France

I was interested to read your article about the inaccuracies of AI search tools, headlined: "AI doesn't have all the answers". This could be contested – by the comedian Eric Morecambe, for example, who would probably argue: "No, it's giving the *right* answers. But not *necessarily* to the corresponding questions."

From David Myers
Commugny, Switzerland

My experience with large language models (LLMs) is that questions about technical systems, such as Windows 11, produce fairly good answers because the information comes from professionally produced documentation. Everything else is a mixed bag. The reason why is evident and not easily fixable. If LLMs are trained on unfiltered data from the web, then they must necessarily be unreliable due to the well-known dictum, rubbish in produces rubbish out.

What value should we place on a human life?

20 September, p 6

From Dyane Silvester
Arnside, Cumbria, UK

Your article on covid-19 vaccines' economic benefits lays out the stark disparity between the value that governments and businesses put on human lives (the lower estimated benefit of $5 trillion), and the value that individuals do ($38 trillion). No wonder so many of us feel that "society" doesn't value or care about us: these figures highlight just how much it doesn't.

On the carbon-capture-and-storage debate

Letters, 11 October

From David Flint
London, UK

Paul Broady suggests plans to capture carbon from the air are a distraction, and we should focus on deep cuts in emissions. He is half right. We do urgently need to make deep and permanent emissions cuts and to keep cutting until we get as close to zero as we can. But this won't be enough.

We are already 1.5°C (2.7°F) above pre-industrial temperatures. The latest science shows that we need to get this down to 1°C (1.8°F), and the only way to do this is to remove carbon dioxide from the air. The limitations of current carbon-capture systems aren't reasons to ignore this option. In fact, we should see these limitations as reasons to invest more in carbon capture R&D.

Fermentation is not just a matter of taste

4 October, p 32

From Guy Cox
St Albans, New South Wales, Australia

As a lover of "mouldy" cheeses, I very much enjoyed Graham Lawton's article on fermented foods, though I would have to dispute that all blue cheeses taste the same – perhaps we can lure him out to Australia to sample some of our offerings.

But you list fish sauce – *nam pla* in Thai – as a fermented food. It may be, but no microorganisms are involved: it is just a product of autolysis, natural enzymes in the salted fish breaking down complex proteins. It's just like your Marmite or our Vegemite. So there isn't really any potential for refinement.

Serious science or just navel gazing?

11 October, p 14

From John Woodgate
Rayleigh, Essex, UK

Your article "Uncovering the ins and outs of belly buttons" must be wrong about the historical lack of study into the umbilicus: haven't millions of people been accused of contemplating their navel? ▮

For the record

▮ **The artefacts associated with newly discovered rock art in Saudi Arabia indicate links with Pre-Pottery Neolithic people in the Levant (11 October, p 14).**

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EIKO OJALA

Your hidden helper

Our lymphatic system has long been overlooked, but it may hold the key to treating everything from dementia to cancer, finds **Carissa Wong**

I PLACED the cold, jade rolling pin under my cheekbone and gently glided it to the edge of my face. To be honest, I felt a bit like a piece of pastry. But my grandma assured me that I was engaging in a serious traditional Chinese practice that would make my skin glow and my face less puffy. It would be more than a decade before face rolling became the next big beauty fad on social media – and several years more before I realised its supposed benefits may hinge on the lymphatic system, a network spanning the entire body, consisting largely of thread-like vessels and bean-shaped nodes.

Despite having been described in the first known medical scientific paper, the lymphatic system remained a mystery for millennia afterwards. Being extremely elusive and incredibly delicate, it is hard to study – the ruby-red blood system, in contrast, got far more attention. "Lymphatic vessels permeate nearly every organ of our body and yet they sit in our tissues practically invisible," says Kathleen Caron at the University of North Carolina at Chapel Hill. Only in recent decades have researchers begun to appreciate the profound role the system plays in health and illness, thanks to advances in imaging techniques and molecular beacons that shine a light on its inner workings.

This growing interest has fuelled discoveries that suggest our lymphatic network could be a secret ingredient in treating some major health conditions, including Alzheimer's disease and cancer. "In the past 20 years, we have experienced a renaissance in lymphatic biology," says Caron. "It would be transformative to harness the powerful roles of lymphatics in keeping us healthy."

The earliest surviving mention of this ghostly web comes from Egyptian hieroglyphs in a treatise from around 1600 BC that refers to swollen masses in the neck and armpits – structures we now recognise as lymph nodes. A millennium later, the Greek physician and philosopher Hippocrates described the vessels running between these structures, noting that the nodes often swell during infections.

It wasn't until the 1700s, however, that we started to understand the lymphatic network as a sort of waste-disposal system. Blood vessels supply your tissues with a clear, yellowy fluid containing oxygen, nutrients and immune cells. As well as nourishing cells, it sweeps up their metabolic waste products along with fragments of damaged cells and pathogens, before draining back into the vascular system. However, about 10 per cent of the fluid remains in the tissues, and this is where lymphatic vessels come in: they collect the leftovers.

Once inside lymphatic tubes, the fluid is known as lymph – derived from the ancient Roman deity of fresh water, Lympha, and ancient Greece's nymphs, creatures associated with clear streams. Lymph travels to a nearby node, of which there are about 500 to 600 distributed throughout our bodies. There, immune cells called phagocytes gobble up much of the detritus and, in turn, activate nearby T-cells to recognise any pathogens or cancer cells that are present. Lymph, along with these activated T-cells, then travels through the lymphatic system, re-entering the blood via major ducts near the heart. Any remaining waste products are eventually filtered out by the kidneys and excreted. The T-cells, however, continue to circulate until they reach sites where they fight off intruders or mutant cells.

"CAN WE CURE DEMENTIA BY IMPROVING THE LYMPHATIC DRAINAGE FROM THE BRAIN?"

Given the lymphatic system's roles in immunity and waste disposal, it seems surprising that scientists long thought it was disconnected from our most vital organ, the brain. But there's a reason. A healthy immune response includes inflammation, which, as well as fighting pathogens, can damage our cells. The brain was thought to have evolved to avoid this collateral damage. It has a structure called the blood-brain barrier to keep pathogens and toxins out, and was seen as "immune privileged", meaning it lacks immune cells. So, it was assumed not to require the immune services of the lymphatic system – and circulating brain fluid was thought to drain out via non-lymphatic routes, including spaces along nerves that run to lymphatic vessels in the nose.

Such thinking meant that, in the late 1700s, when anatomist Paolo Mascagni injected corpses with mercury and discovered silvery branches, which he claimed were lymphatic vessels bordering the brain, he wasn't taken seriously. It would be more than two centuries before two groundbreaking studies upended the scientific consensus. In 2015, Kari Alitalo at the University of Helsinki in Finland and his team made a surprising discovery while exploring how T-cells move around the brain, which we now know has many immune cells. They noticed that the cells, which they had labelled with a fluorescent green marker, lined up in a vessel-shaped arrangement in the dura mater, the outermost of three membranes – collectively known as the meninges – that are wedged between the brain's surface and the skull.

Taking a closer look, the team found that the structures had all the features of lymphatic vessels, and drained fluid into so-called cervical lymph nodes in the neck. Just two weeks later, Jonathan Kipnis at Washington University in St. Louis, Missouri, and his ›

colleagues reported finding the same network, this time using mice genetically engineered to have fluorescent lymphatic vessels. "It was this eureka moment for the entire field," says Sandro Da Mesquita at the Mayo Clinic in Jacksonville, Florida, who wasn't involved in either study.

In 2017, Kipnis's team confirmed that humans also have this meningeal lymphatic network. Soon, a wave of rodent studies showed that the vessels become thinner, shorter and less numerous with age. Such degeneration slows the rate of fluid drainage from the brain and worsens cognitive decline. "Ageing leads to regression of these vessels," says Da Mesquita. "In a very old mouse, the lymphatic system that drains the brain is very impaired, which is even more interesting because in most peripheral tissues you don't see that [so much]."

Crucially, reversing such decline brings cognitive benefits. For instance, Da Mesquita and Kipnis injected the brains of old mice with the genetic code for a protein called VEGFC, which can dilate lymphatic vessels. This boosted the drainage of brain fluid through the meningeal lymphatic vessels and enhanced the animals' performance in memory and learning tests. The same approach partly reversed cognitive decline in mice with features of Alzheimer's disease, the most common form of dementia. It seemed to work by boosting clearance of a toxic form of beta-amyloid, a protein implicated in the condition.

"RESEARCHERS ARE HARNESSING LYMPH NODES TO GROW ORGAN TRANSPLANTS"

Boosting drainage

Such findings have prompted scientists to wonder whether lymphatic ageing also impairs cognition in people. There are very early hints that it does. In a study out earlier this year, Sarosh Irani at the Mayo Clinic, Da Mesquita and their colleagues analysed lymph extracted from the cervical lymph nodes of 25 people aged between 22 and 84 who didn't have neurodegenerative disease. They discovered that levels of tau, a protein linked to Alzheimer's, seem to decrease in lymph nodes with age. Irani says this suggests that age-related deterioration of the meningeal lymphatic vessels may reduce their ability to drain and filter out problematic proteins, so they accumulate in the brain, where they could contribute to neurodegenerative conditions like dementia.

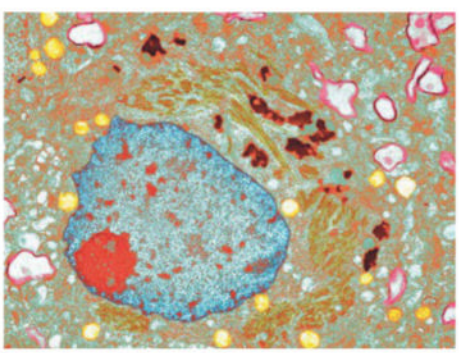
"Some of these diseases, at least in some cases, might even be starting or being partly triggered by degeneration of the lymphatics," says Irani. Da Mesquita cautions that much larger studies involving thousands of people are needed to verify such potential links. Nevertheless, these early findings hint at a tantalising possibility. "There's this big therapeutic angle," says Irani. "Can we cure dementia by trying to think of how you might improve the lymphatic drainage from the brain?"

Indeed, some researchers are already pursuing this idea. In a study in May, Rong Hu at the Army Medical University in China and colleagues recruited 26 people with Alzheimer's disease to undergo surgery to their cervical lymphatic vessels that boosted the drainage of fluid from the brain. One month later, the participants performed slightly better in memory, attention and language tests, with about 60 per cent of their caregivers noticing such improvements. But the study was small and lacked a control group of participants with Alzheimer's disease who didn't undergo the procedure, plus the surgery is highly invasive.

In search of a simpler method, Gou Young Koh at the Korea Advanced Institute of Science and Technology in South Korea and his colleagues recently found that gently massaging lymphatic vessels around the face and neck in a very specific pattern could boost brain fluid drainage in old mice to the levels seen in young mice. The researchers didn't assess how this affected the animals' cognitive abilities, but they plan to explore whether the technique can improve such abilities in mice with features of Alzheimer's disease.

Cancer is another key area where tapping into our meningeal lymphatic system could help. After learning about the 2015 discoveries, Eric Song at Yale University and his colleagues wondered whether the VEGFC approach might boost immune responses to glioblastoma, the deadliest form of brain cancer. To put this idea to the test, they injected the genetic code for VEGFC into the brains of mice with this tumour, along with an immunotherapy called anti-PD-1. A control group got just the anti-PD-1 injection and the genetic code for a fluorescent protein that

SUSUMU NISHINAGA/SCIENCE PHOTO LIBRARY



THOMAS DEERINCK, NCMIR/SCIENCE PHOTO LIBRARY

Above: Lymph nodes remove tau proteins from the brain, which can clump together in neurons in Alzheimer's disease

Below: People with Alzheimer's disease could benefit from improved lympahtic drainage

ELISABETH SCHNEIDER CHARPENTIER/SCIENCE PHOTO LIBRARY

doesn't affect the lymphatic system. Three months later, about 20 per cent of mice from the latter group had survived. In the former, the figure was 80 per cent – in some cases, their tumours had completely disappeared. "We were over the moon," says Song.

Further analysis revealed that the treatment probably worked by enhancing the drainage of cancer proteins through the meningeal lymphatic vessels into the cervical lymph nodes, enhancing the activation of cancer-killing T-cells that then migrated into the brain, says Song. That's not all. Mice that survived their initial tumours were also able to resist a subsequent injection of brain cancer cells, suggesting the treatment generated lasting immunity.

But there is one problem with the VEGFC approach. It can also enhance the growth of blood vessels, which is known to help tumours spread to distant sites. To address this, Song and his colleagues at the biotechnology start-up Rho Bio have developed an altered version of VEGFC that only acts on lymphatic vessels. They are now testing its safety in non-human primates and hope to trial it for a range of conditions, including brain cancer and dementia in humans.

Lymphatic therapies could treat cancers beyond the brain, too. Natalie Livingston at Massachusetts General Hospital and her colleagues have developed injectable artificial lymph nodes that boost immune responses against tumours in mice. The approach involves extracting T-cells from a mouse and mixing them with a gel containing a cocktail of proteins that activate T-cells to destroy the cancer. This mixture is then injected back into the mouse to create a factory of cancer-killing T-cells – the artificial lymph node. "It's about half a centimetre in diameter, and forms just like a little mosquito bite under the skin," says Livingston. This procedure nearly halved the size of colon tumours in mice, and improved survival rates compared with a placebo implant. And it worked just as well against melanoma, the deadliest form of skin cancer.

ANA ALVES/ALAMY

The traditional Chinese technique of gua sha supposedly stimulates the lymphatic system

Internal bioreactor

Lymphatic therapy doesn't stop there, though. Other researchers are harnessing lymph nodes to grow organ transplants. The approach involves implanting cells from a donor organ into a lymph node near the failing organ. Nourished by the lymphatic system's rich supply of blood, the cells grow into a mini organ that eventually replaces the lymph node and supplements the damaged tissue. "It turns out that the lymphatic system and lymph nodes are just incredibly effective bioreactors for a variety of tissue types," says Michael Hufford, CEO at Lygenesis.

In experiments with mice, his team has shown that such mini organs can reduce symptoms of liver disease and kidney disease, as well as type 1 diabetes where there is damage to the pancreas. The body can afford to lose one lymph node and the rest of the lymphatic system is unaffected, so the technique doesn't seem to cause any side effects, says Hufford. His team is now trialling the approach in 12 people with end-stage liver disease, four of whom have now received their implants. The results should be available within the next two years.

It is already clear that lymphatic biology has huge and exciting potential in treating disease. But there is still much we don't understand. One key question is the degree to which lymphatic vessels differ across the body. In an ongoing study that has yet to be published, Caron is exploring how gene activity varies between lymphatic vessels associated with eight organs, including the lungs, liver and heart. It is the first comparative study. "Prior studies looked at gene expression profiles in just one organ," says Caron. "We found a lot of very fascinating differences that really underscore just how different lymphatic vessels are throughout the body."

In another ongoing study, Caron is generating a list of protein receptors on lymphatic vessels that are potential targets for drugs. This could reveal new ways of manipulating our lymphatic system – it may even uncover previously unknown ways that existing treatments work. "Lots of drugs might be acting on lymphatics and we just didn't know it," says Caron. Supporting this idea, her team has recently shown that many migraine drugs boost the drainage of brain fluid through meningeal lymphatic vessels. "It's awe-inspiring when you consider just how much we need to learn about this understudied vascular system that is so critical for keeping us healthy," she says.

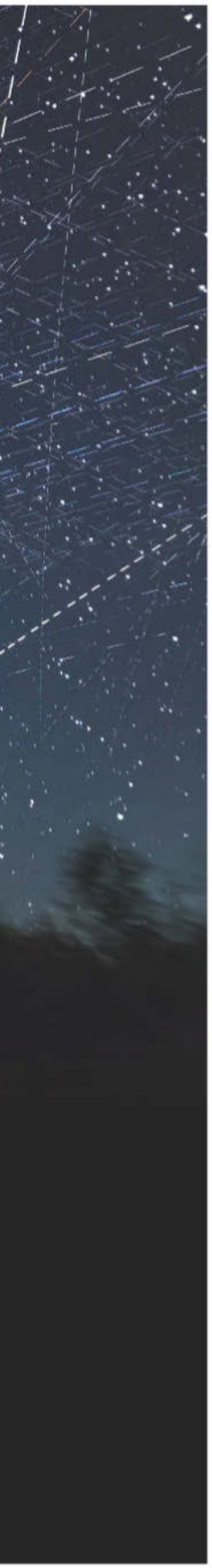
All this may leave you wondering whether popular "lymphatic drainage" practices might actually work. Here the news is less rosy. Admittedly, face rolling can temporarily sharpen your jawline by increasing fluid drainage, but there is little good-quality evidence to back up health claims for things like reduced inflammation or cellulite removal. So, although I have come to marvel at my lymphatic system, I won't be including a jade rolling pin in my morning routine. Sorry, Grandma! ▮

Carissa Wong is a health reporter at *New Scientist*

ALAN DYER/VW PICS/SCIENCE PHOTO LIBRARY

Burning up

Satellites are incinerated in the atmosphere at the end of their lives, creating pollution that will only get worse as the skies get more crowded, finds **Tereza Pultarova**



Our night sky is becoming increasingly crowded

THINK of pollution and your mind's eye might conjure up images of smoke spewing chimneys, car exhausts and those sewer outflows you see on beaches. What probably doesn't spring to mind is the mesosphere, a slice of sky far above the height any aeroplane flies. And yet a growing chorus of scientists are sounding the alarm that this could be the site of a worrying new form of pollution.

There are currently more than 15,000 satellites zooming around our planet, and almost all are destined to be de-orbited, a euphemistic way of saying they will burn up in the atmosphere. In doing so, they will release clouds of metals, soot and reactive chemicals that could have worrying effects, including damaging our protective ozone layer. "It is like a mini geoengineering experiment," says atmospheric chemist Eloise Marais at University College London.

Few scientists think this is causing serious harm just yet. The trouble is, it soon could be, as the number of satellites continues to soar. That is why researchers are now rushing to get a handle on this problem and figure out exactly what this new pollution consists of, what its effects will be and what we can do about it.

Over the past decade or so, satellite designs have been miniaturised and the cost of launching them has plummeted, thanks to the rise of reusable rockets. Both factors have led to the launch of a huge number of satellites (see "Orbital explosion", page 35). Foremost among them is the Starlink megaconstellation, which currently consists of around 8000 satellites used to provide broadband internet. These objects are in low Earth orbit, many at an altitude of approximately 550 kilometres.

The number of satellites is expected to keep growing fast. Amazon is developing a rival to Starlink called Project Kuiper, which currently has around 100 satellites and approval to launch some 3000 in total. China is doing likewise, with plans to grow its version, called Guowang, to 13,000 satellites. Add up all the plans and it seems that low Earth orbit could get a lot more crowded very quickly. Some estimates suggest there could be a further 70,000 satellites there by 2030.

Why does this pose a problem? The lifetime of these satellites is often only about five years, partly because they are designed to carry limited fuel, which they need to stay aloft, and partly because operators want to upgrade their fleets with newer, more capable tech. To prevent the old satellites from cluttering near-Earth space, risking collisions, they direct them into the atmosphere to burn up.

At the moment, we aren't talking about a vast amount of material. According to the European Space Agency, about three old satellites or rocket stages perish in the atmosphere every day. Astrophysicist Jonathan McDowell at the Harvard–Smithsonian Center for Astrophysics in Massachusetts, who tracks satellite launches and re-entries, says he estimates that around 900 tonnes of space debris may be vaporising in the upper atmosphere every year. This equates to 5 per cent or so of the mass injected naturally by meteoroids.

That may not sound troubling, but researchers worry about the cocktail of human-made materials satellites leave behind. One of the big concerns is aluminium, which constitutes up to two-fifths of the average satellite. When burned in air, aluminium is converted to aluminium oxide, commonly known as alumina. We have known for many years that alumina particles in the atmosphere react with and deplete ozone, the gas known for absorbing ultraviolet radiation from the sun that would otherwise be harmful to life. In the 1990s, researchers found that the alumina released from solid rocket boosters used in Space Shuttle launches caused miniature, temporary ozone holes in the stratosphere minutes after each of those rocket passages. On top of that, alumina is reflective, and so can influence atmospheric temperature. We know that about 10 per cent of aerosol particles in the stratosphere contain aluminium and other metals emanating from the burn-up of satellites and rocket stages.

"Every year, we are seeing emissions from satellite burn-ups getting bigger"

Satellite de-orbiting also produces black carbon or soot, which directly absorbs sunlight, and so warms the atmosphere. True, industry on the ground produces vastly more soot than satellite pollution does, but there is a complication that could make the latter far more damaging. Satellites typically burn up ›

in the mesosphere at an altitude of 50 to 80 kilometres. It is thought that particulates injected here can potentially stay in circulation, gradually filtering down through the atmosphere for years, depending on their size and composition.

As they slowly descend to Earth, they pass through the stratosphere, where most of the planet's protective ozone resides, potentially triggering ozone depletion. "Rain cleans up the lower atmosphere fairly quickly," says Marais, "but up there, it's much more conducive to accumulating." A 2022 study led by her and her colleagues estimated that, due to its long lifetime in the atmosphere, soot released at high altitudes from rockets burning the most common type of rocket fuel may be up to 500 times more warming than that emitted by cars or passenger planes. *New Scientist* contacted both Amazon and Starlink to ask about their views on satellite pollution generally. Starlink did not respond and Amazon gave no comment.

Climate warning

Space sector emissions inventories suggest that prior to 2020, metal and soot pollution levels in the atmosphere were growing by about 6 per cent per year, according to Conor Barker, one of Marais's colleagues at University College London. But more recent data reveal this type of pollution is now growing more than three times as quickly. This could have dramatic consequences for Earth's environment. "Every year, we are seeing those emissions getting bigger," says Barker. "Especially since 2020, the growth has been quite steep and getting steeper as we see many more satellites launched and de-orbited and larger rockets pumping more pollutants into the upper atmosphere."

Other researchers are turning their attention to modelling the large-scale effects these pollutants might have on Earth's climate. Earlier this year, a team of researchers led by Christopher Maloney at the University of Colorado Boulder used computer simulations to model what would happen if the number of short-lifetime satellites in orbit were to exceed 60,000 – well within the limits of existing predictions. The researchers found that the corresponding rise in concentration of atmospheric alumina would see the mesosphere warm by 1.5°C, and there would also be a 10 per cent reduction in speed in the high-level winds of the southern hemisphere polar vortex.

15,139

The number of satellites currently in orbit around Earth
Source: UN Office for Outer Space Affairs

70,000

The number of further satellites projected to be launched by 2030
Source: Goldman Sachs

3

Number of satellites that burn up in the atmosphere each day
Source: European Space Agency

10%

Proportion of particles in the stratosphere that contain metals that originated in satellite burn-ups, as of 2023
Source: doi.org/gswhv8

This plasma wind tunnel is used to simulate how satellites burn up in the atmosphere

STEFAN LOEHLE

Maloney emphasises that these results shouldn't be taken as a hard and fast prediction. "Even though we used alumina in our simulation, there is not even a general consensus about what type of aluminium products we are going to get," he says. Other possibilities include aluminium monoxide and aluminium hydroxide, which may be less harmful than the ozone-depleting alumina. But his team's results do suggest there is potential for satellite pollution to have a measurable effect on the dynamics of the atmosphere.

Atmospheric chemist John Plane at the University of Leeds, UK, says that existing predictions of the space industry's growth suggest that the amount of incinerated space trash could easily grow by a factor of 50 within the next decade. Scientists have just a few years to get ahead of the problem. "These processes need to be explored in the laboratory so that we have the necessary physiochemical data to model them properly," he says.

One of those doing exactly that is Stefan Löhle, who heads the plasma wind tunnel laboratory at the University of Stuttgart in Germany. For 20 years, he and his team have used wind tunnels to ensure spacecraft survive atmospheric re-entry. But recently they have turned their interest towards satellites deliberately designed for a fiery death, in an effort to properly understand the physical process of disintegration.

Using a 5-metre-long wind tunnel, Löhle and his colleagues melt chunks of aluminium in a flow of plasma mimicking the fiery conditions during a satellite re-entry at altitudes of 60 to 80 kilometres. They compare the light given off by the chunks in the tunnel with spectroscopic measurements of real satellite break-ups obtained from Earth and from a handful of aircraft observation campaigns conducted in recent years. They then tweak the conditions in the tunnel until the simulated spectra match the real thing – and then analyse what happens in detail.

Although humankind has been burning stuff in space for almost 70 years, observations of satellite re-entries from Earth and from aircraft have so far revealed very little about this fiery process. Löhle says satellite demise begins at 120 kilometres and is mostly complete at 50 kilometres above Earth. "You have an aluminium structure that melts and forms droplets. But not all of these droplets completely evaporate into aluminium oxides. Some of

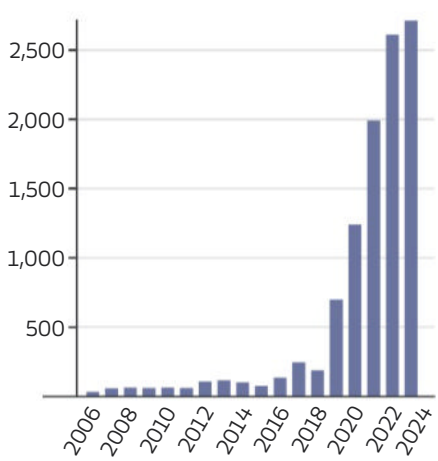
JSC/NASA

What goes up must come back down

"Simply changing the trajectory of a satellite as it de-orbits could change how it burns up"

Orbital explosion

The number of satellites launched each year started to grow steeply from about 2020. Estimates suggest there are more than 15,000 currently in orbit



SOURCE: UN OFFICE FOR OUTER SPACE AFFAIRS

them may condense into solid particles, nanometre or micrometre in size, and just float down to the ground where they won't be harmful."

Understanding the exact nature of these particles, their shapes, sizes and subsequent interactions with the atmosphere, is the goal of this research. That, in turn, will inform the work of modellers such as Barker, Marais or Maloney, who will have more accurate inputs for their climate impact studies.

An easy fix?

Löhle's work could also help with one possible solution to the problem of satellite pollution. In principle, simply changing the trajectory of a satellite as it de-orbits could change the air resistance it experiences and so how it burns up, potentially reducing the amount and composition of material left behind. One of the next steps for Löhle and his team will be to experiment with modifying the conditions in the wind tunnel to mimic various re-entry trajectories and investigate what happens. Studies like this could pave the way for optimising the re-entry process, says astronautics expert Minkwan Kim at the University of Southampton, UK, even if the best strategy is as yet unclear. "Shallow re-entries may reduce the formation of metal oxides and produce more metallic vapour and aerosols," he says. On the other hand, they tend to increase generation of nitrogen oxides, which, like aluminium oxide, deplete ozone.

There are plenty of other ideas on the table. Among them is a new type of very low-orbiting satellite powered by atmosphere-breathing electric propulsion. This is an early stage design, but in principle, such satellites would be able to stay aloft for very long periods, using the gases in the air to power them, meaning there would be far fewer de-orbits required. One startup based in Reading, UK, called New Orbit is developing satellites along these lines.

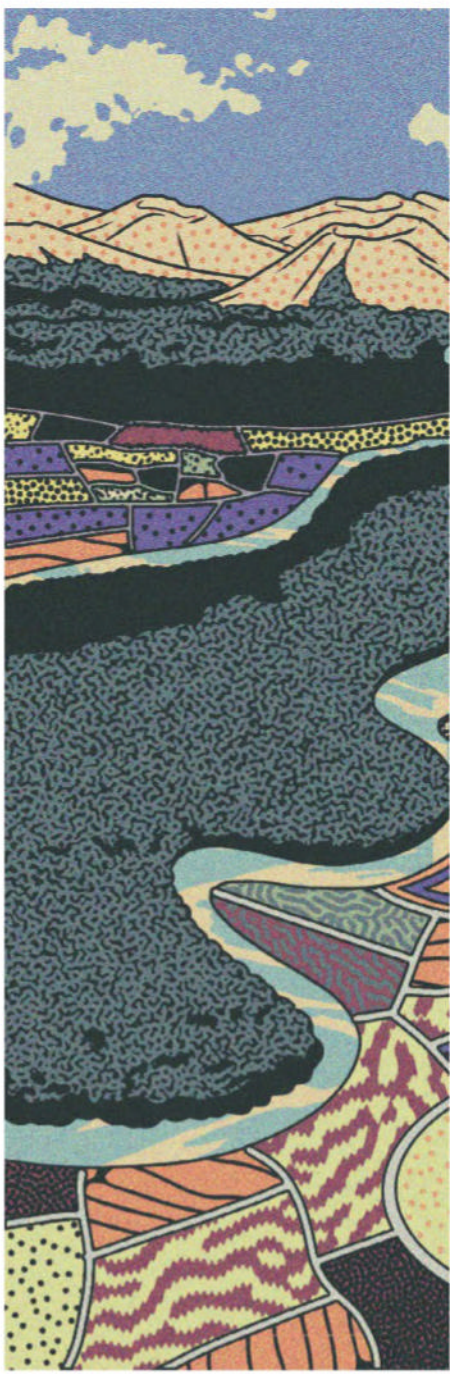
We may need to go further still, shifting away from a model where satellites are disposable and towards a circular economy in space. The idea would be that satellites are serviced, upgraded, refuelled and, ultimately, even recycled in orbit. The European Space Agency is already talking up this idea and working on a mission called RISE, which is designed to demonstrate the ability to dock with and control the orbit of a geostationary satellite. These orbit much higher than the satellite constellations that are growing fast, but it could be a first step towards in-orbit refuelling. There has been speculation that China has already attempted in-orbit refuelling of a satellite.

Satellite pollution may not have become a serious threat yet, but for Löhle it isn't OK for companies to put this concern on the back burner. "It's all a bit like, 'let's think about this later'," he says. "But later is now. The material that we are putting into our atmosphere may have significant impacts. Yet we have barely understood how the fragmentation of satellites works." ▮

Tereza Pultarova is a science and technology journalist specialising in space, aerospace and defence technologies

Landscape of consciousness

Robert Lawrence Kuhn explores what mapping 350 theories of consciousness reveals about free will, artificial intelligence and life after death



THOMAS HAYMAN

CONSCIOUSNESS is the ultimate question of existence. Nothing is more essential than our experience. Yet we have no consensus, and perhaps no clue, about what it actually is.

The trouble, in part, is that experts usually become invested in one theory, blinding themselves to alternative explanations that could aid progress. Instead, I embrace the diversity of consciousness theories across science, philosophy and religion – so long as they are built on clear arguments. In this way, over many years, I have charted more than 350 theories (and counting) onto a "landscape" of consciousness, which I will help you to explore.

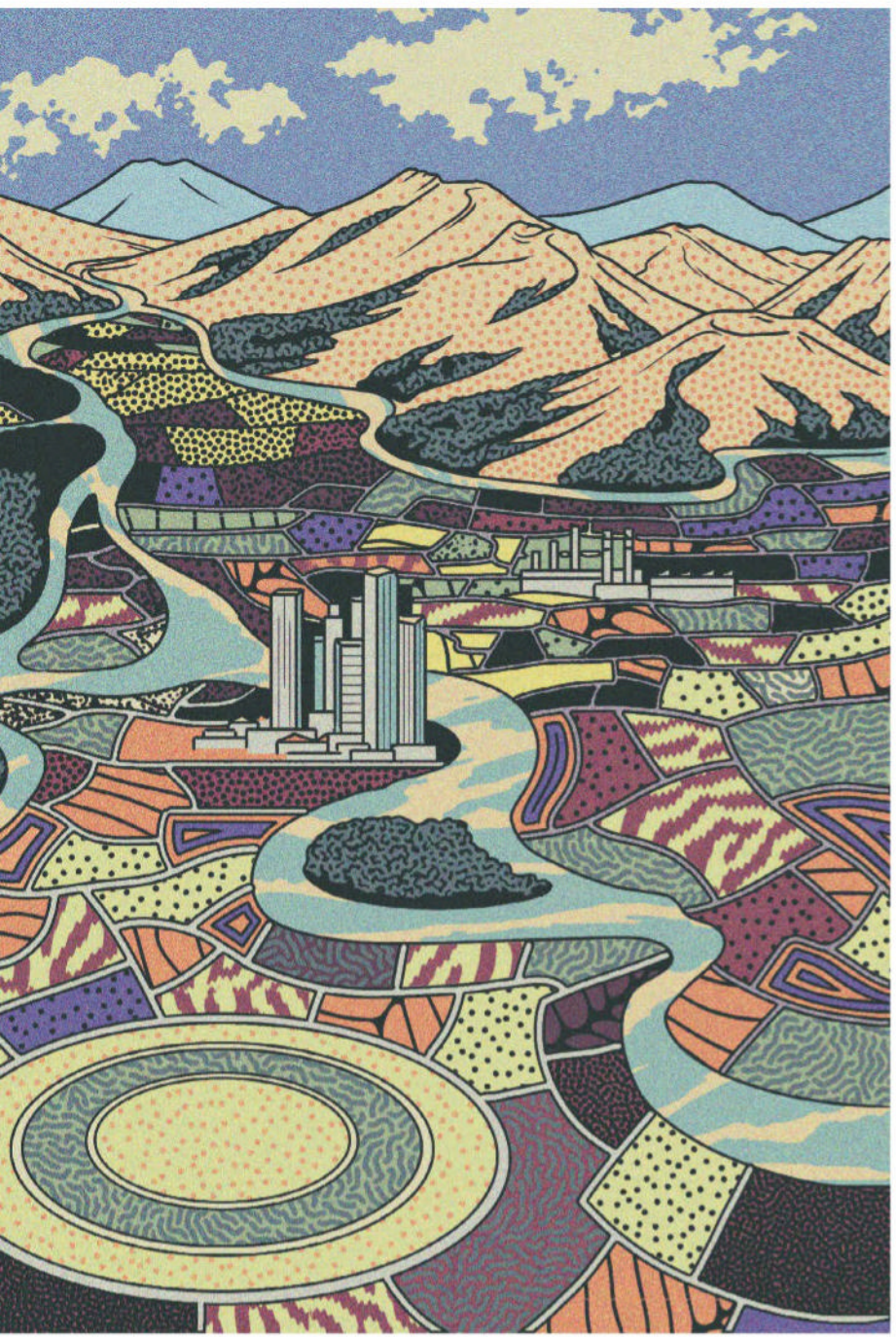
From materialism, where only physical states are real, to idealism, where only mental states are real – and everything in between – it will become apparent, as we wander through these heady fields, how much is at stake. That's because whichever theory of consciousness you favour determines many of your core beliefs about the world, such as your opinions on the nature of free will, the possibility of life after death and whether artificial intelligence can attain consciousness.

Mapping this landscape, I marvel not only at the sheer number of possible theories, but also at the astonishingly divergent scales and places where the magic of consciousness could make its home. Often, neuroscientists assume that experience emerges, somehow, from neurons firing in the brain, but there are many alternative theories – some of which have consciousness as fundamental, and some which have physical reality as an illusion. At the micro-extreme, does consciousness arise when quantum wavefunctions collapse into concrete reality? Or, on the grandest scales, is the cosmos itself conscious in some sense?

To begin making sense of what consciousness is, you have to specify what you are asking. AI pioneer Marvin Minsky called consciousness "a suitcase term", meaning that people toss in whatever they wish, so that it becomes swollen with related but confounding concepts like perception, attention, wakefulness, memory, emotion and intelligence. I mean none of these. By consciousness, I mean "phenomenal consciousness": your what-it's-like inner sense; your private feelings. It is the sight of your newborn daughter, swaddled; the sound of Mahler's *Symphony No. 2*; the smell of garlic cooking in olive oil. These interior experiences are called "qualia", and they are the crux of the conundrum.

I first became absorbed in this question in my early teens, leading me to pursue a PhD in brain research at the University of California, Los Angeles, in the mid-1960s. Back then, the origin of consciousness wasn't a meaningful question that neuroscientists knew how to ask. More recently, as the creator and host of the public television series and digital resource *Closer to Truth* (co-created and directed by Peter Getzels), I have discussed consciousness with more than 200 scientists and philosophers over almost three decades.

All of this has led me to try to express the full breadth of human discovery, contemplation and imagination on consciousness in this landscape. In a peer-reviewed, open-source paper published last year, I assembled well-



“Can physical states ever explain mental states?”

known theories and curated lesser-known theories that possess some combination of originality, rationality, coherence and – admittedly – charm. In collaboration with physicist and neuroscientist Àlex Gómez-Marín, digital strategist D.J. Smith, concept designer Deniz Cem Önduyg, and editors Sean Slocum and Sandra Derksen, this subsequently expanded into an interactive, comprehensive website called the Landscape of Consciousness. Some of the hundreds of theories we compiled might seem bizarre. All highlight humanity’s restless quest to comprehend the mind and apprehend reality. My hope is that whatever consciousness is, it exists – somewhere, somehow, some way – on this landscape.

Most neuroscientists, naturally, assert that consciousness is entirely the output of the brain, emerging from the firing of neural impulses and the flowing of neurochemicals. But even as knowledge of brain biology accumulates, a question persists: can physical states ever explain mental states? Philosopher David Chalmers referred to this as the “hard problem” of consciousness, and its intractability leads us to forks in the landscape.

What makes you conscious?

This first decision comes down to whether a theory is dualist or monist. Dualism, an idea most scientists steer clear of, posits the mental and physical as two deeply distinct substances, neither reducible to the other. For instance, traditional Abrahamic religions – Judaism, Christianity and Islam – feature a “soul” along with the physical body or brain. On the other hand, monism says that reality in all its manifest forms consists of only one kind of “stuff” at its deepest level. Philosopher Bertrand Russell proposed that a single set of properties underlies both consciousness and the fundamental entities of the physical world.

Two monisms sit at opposite ends of the landscape. On one side, materialism claims that only things that obey the laws of physics are real, so mental states must be wholly explained by physical states. Meanwhile, on the other side, idealism argues that the mental is fundamental and the physical is derived from this. This would mean that physical reality is a manifestation of cosmic mind. For example, most Hindu traditions regard consciousness alone as ultimate and the physical world as a mere illusion.

Among materialism, dualism and idealism, somehow, lies panpsychism, the idea that ›

fundamental fields or particles of the physical world are imbued with some kind of awareness or proto-consciousness.

The second decision separating these categories of consciousness lies between physical theories that conform to the classical laws of physics and principles of neurobiology, and those that don't. The idea that the brain works like a computer and that consciousness results from neurons communicating in complex feedback loops are examples of such conformist theories. Whereas theories based on, say, the idea that information is a fundamental property of reality, are non-conformist because they operate outside the scope of typical scientific ways of thinking about consciousness. Giulio Tononi's integrated information theory, for instance, considers information to be a fundamental aspect of reality and sees consciousness as identical to the intrinsic causal power structure of that information.

Reasoning in this way led me to separate the landscape of consciousness into 10 broad categories that are arrayed roughly from physicalist to non-physicalist (see "Categories of consciousness", right). At the far end, another category collects theories that are informed by parapsychological phenomena, such as near-death experiences, along with altered states of mind, such as meditation and psychedelics. I claim no privileged perspective for these categories: other choices are possible, and exactly where to place some theories remains open to debate.

Nevertheless, these categories offer a foundation from which to explore further forks in the road. At this next juncture, we can ask: is consciousness fundamental and primitive, or accidental and derived from something else?

If fundamental and primitive, then consciousness can't be totally reduced to deeper levels of explanation. There can be partial explanations, but there will always be some aspect of our experience that can't be modelled by biology, chemistry or physics. Every theory that is dualist, panpsychist or idealist agrees that we can study the biological facets of consciousness by studying the brain – but they all claim this will never lead to a complete understanding. In other words, there are limits to how far the scientific method can take us.

If accidental and derivative, then progress beckons, leading us to another split: is consciousness real or an illusion? It sounds counterintuitive, but arguments are made that consciousness is a trick of the mind. If so, then

Categories of consciousness

Over 350 theories are divided into 10 categories, each of which regards consciousness in a distinct way. The first category (Materialisms) contains almost half of these theories and is further divided into 12 subcategories.

1 Materialisms

Consciousness is entirely physical, solely the product of biological brains and all mental states can be wholly explained by physical states – which are fundamental fields and particles deep down.

2 Non-reductive physicalism

Consciousness is entirely physical, solely the product of biological brains, but mental states or properties can't be reduced to physical states or entirely explained by physical laws.

3 Quantum and dimensional

Fundamental physics – especially quantum mechanics – plays a necessary role in the generation of consciousness, beyond the widely accepted role of quantum mechanics in all physical entities.

4 Information

Information is the basic "stuff" of reality and is more fundamental than matter, energy and space-time. Consciousness arises from or is identical to informational structures or processes.

5 Panpsychisms

The essence of consciousness or proto-consciousness is a primitive, non-reducible feature of every part of physical reality, similar to the fields and particles of fundamental physics.

6 Monisms

All of reality consists of exactly one substance, kind, stuff, ground or being that manifests in multiple ways. Monistic theories must express everything mental, as well as everything physical.

7 Dualisms

Dualistic theories require two radically distinct parts: a physical brain and a separate, non-physical substance that is independent of the brain and is also not of the physical world.

8 Idealisms

Consciousness is the ultimate reality. Everything else, including all physical worlds and all that they contain, is derived from consciousness or is an illusion.

9 Anomalous and altered states

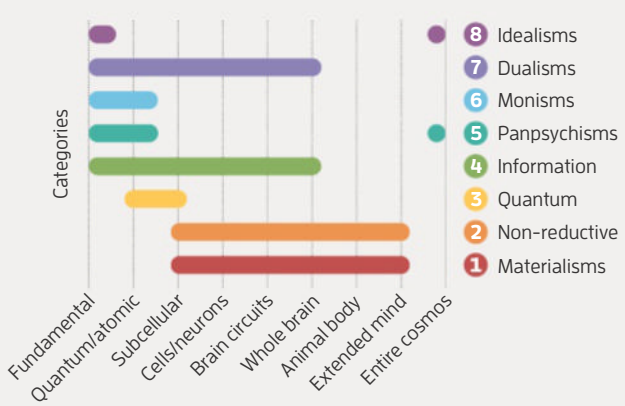
Extrasensory perception, parapsychological research, out-of-body experiences, near-death experiences, meditation and psychedelics can inform or reveal theories of consciousness.

10 Challenge

Explaining consciousness is beyond human capacity, or demands radically novel frameworks.

Where does consciousness reside?

The "magic" of consciousness could occur across a vast range of spatial scales, from the most fundamental, below the quantum realm, to the span of the entire cosmos.



SOURCE: ROBERT LAWRENCE KUHN AND ÀLEX GÓMEZ-MARÍN

the consciousness conundrum dissolves, or at least deflates. Philosopher Keith Frankish's illusionism, for instance, is the idea that our inner experience of qualia isn't what it seems; qualia aren't intrinsic and fundamental features of the mind, but rather brain-generated impressions.

Next, if consciousness is real yet isn't fundamental, then it is likely to be emergent. Emergence means that the higher-level properties of a system, such as consciousness, arise somehow from the complex interactions of its lower-level components. Water is wet, for instance, but individual water molecules aren't. We can model how numerous water molecules combine to become wet, so we call this kind of emergence "weak", as it is still subject to complete scientific explanation. Materialist theories of consciousness generally tend to be weakly emergent. On the other hand, if consciousness is strongly emergent – rather than weakly emergent – it would always escape reductive physical explanation. Many of these theories fall under the category of "non-reductive physicalism".

Cosmic consciousness

Could there be a middle path, where consciousness wasn't fundamental to begin with, but, once evolved and emerged, becomes inevitable – not a mere cosmic fluke? The universe, some say, naturally tends towards self-awareness. Physicist Paul Davies suggests that quantum mechanics, in which observers seem to distill current reality out of many past possibilities, offers a conceivable mechanism. The idea, rooted in the work of physicist John Wheeler, is that if consciousness eventually saturates the universe, then future observers could determine past events as far back as the big bang, thereby granting consciousness genuine cosmic significance. But most theories that embrace this radical notion go beyond the physical. Theologian and palaeontologist Teilhard de Chardin, for example, envisioned the evolution of consciousness as the foundation of a grand cosmic system.

Some of these ideas may sound outlandish; most can't be subject to experiments, but they remain coherent theories, believed by some and at least plausible to others. The sheer diversity of theories becomes apparent when you plot these 350 theories from the most materialist to the most idealist, and across the vast scales where they posit consciousness to exist.

DAS/SOPA IMAGES/SHUTTERSTOCK

Most Hindu traditions see consciousness as essential and the physical world as an illusion

Yet materialism, which strictly adheres to the scientific method, is the most extensive consciousness category, housing almost half of the over 350 theories in 12 distinct subcategories. This should come as no surprise: there are more ways to explain consciousness with physical models than with non-physical models. Indeed, innovation must also abound if materialist theories are to address the never-fading question of how the brain gives rise to experience. In one neurobiological theory, a mental state becomes conscious when it "wins" competitive access to a global workspace in the brain, which broadcasts this state to other brain areas. Electromagnetic field theories, on the other hand, say that consciousness is identical to, or derived from, patterns of electrical currents across the brain.

The landscape of consciousness isn't just a collector's cabinet for gawking at this bewildering array of theories; it is a field lab for exploring profound questions about existence.

Take the heated debate over whether artificial intelligence can become conscious (AIC). This question can't be understood – much less answered – unless you are aware of what category or theory of consciousness you are assuming. Besides, given how challenging it is to devise a test that distinguishes actual AI awareness from pretense, it is insightful to assess how plausible AIC is in this way.

"The landscape of consciousness is a field lab to explore profound questions about existence"

Most AI experts are materialists who subscribe to the theory of computational functionalism, in which the brain and its outputs, including consciousness, are computational in nature, and if the function is reproduced precisely, so is the output, regardless of whether that happens in neurons or computer chips. Other materialist theories, however, privilege life. Embodied and enactive theories, for example, see mind arising from the interaction of brain, body and environment. In this case, physical life forms engaging with the world are the key to the consciousness emerging.

Ultimately, though, there is no difference in the materialist outcome: AIC is inevitable. The only difference is the steps involved and the timeline they require. If computational functionalism is correct, it is a matter of finding those functions, and the timeline is shorter. If life is required, then life must first be artificially created and manipulated, increasing the timeline.

In fact, for most consciousness categories, AIC can be viewed as a technical challenge of one sort or another – although the complexity of this challenge is often wildly underappreciated. For quantum theories of consciousness, AIC also seems almost certain, and the time taken to get there may be accelerated by building quantum computers. Even within panpsychist theories, AIC is likely because consciousness is woven into the fabric of reality. We don't know how these micro-experiences could be ›

combined into macro-minds, but nothing, in principle, should prevent us from identifying and replicating it.

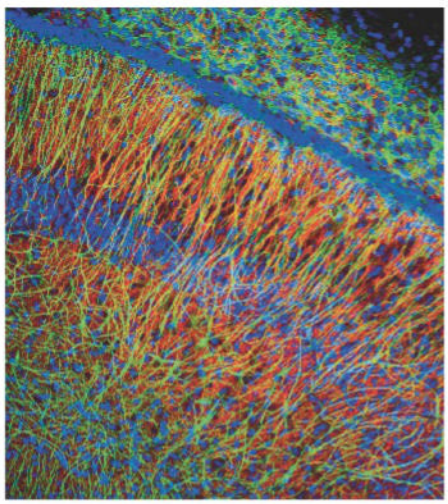
The only real exception to the likelihood of AIC lies with dualist theorists. A radically separate, non-physical substance would – in almost all cases – prevent this from happening, no matter how sophisticated technology becomes.

Living forever

Similar reasoning applies to the possibility of virtual immortality, which requires the creation of a persistent, first-person digital version of our minds that survives death. But virtual immortality is at least one step more difficult and more remote than AI consciousness, because the technological mastery required is far more daunting. Virtual immortality requires duplicating a specific individual consciousness with innumerable qualities that neuroscientists are only beginning to pinpoint, whereas AIC could take many forms.

But virtual immortality isn't the only option when it comes to our perennial quest to survive death. Your consciousness could conceivably continue to exist without any physical brain or body. According to dualism, life after death (in some sense) is certain because our individual consciousness is a non-physical substance that is preserved. Under idealism, even though everything is essentially mental, an individual's consciousness might not remain the same: it could become blurred or blended with some grander cosmic consciousness upon death (or be reincarnated, as some Eastern traditions teach). On the flip side, materialism makes it almost impossible for consciousness to naturally survive death as it would disintegrate along with our biological brains – a blunt reality that motivates some materialists to strive for virtual immortality.

So, take your pick of theories, but be warned that you can't take your pick of implications (see "Existential implications of consciousness", below). Moreover, you might not even have absolute freedom to make that choice. That's because these categories are also consequential when it comes to the weighty question of free will. I mean free will in the "libertarian" sense that past states or laws don't determine some human choices – we genuinely could have done otherwise. According to materialist theories, this kind of free will is unlikely because the regularities of physical laws mean that every physical effect has a prior physical cause. Free will becomes plausible in quantum theories of consciousness because consciousness could leverage the vast potential of quantum effects, such as superposition and entanglement, that aren't yet well understood. And if you are an idealist who believes that the mental causes the physical, then physical states cannot constrain mental states, so you almost certainly have the freedom to choose a path into the future as you please.



DR. CHRIS HENSTRIDGE/SCIENCE PHOTO LIBRARY

Many believe consciousness comes from neurons firing in the brain

All I ask is recognition that whatever theory you land on must be what philosophers call an "identity theory". This means that if you remove whatever causes consciousness, then you also lose consciousness itself – as surely as removing the Morning Star loses the Evening Star, because both are Venus. In other words, in every sentient creature, something just is consciousness.

I have come to love this blizzard of theories because I take consciousness to be the central question of existence, regardless of its ultimate answer. If the deep nature of the world pivots on the question of whether reality is purely physical or not, consciousness likely determines which way the world turns. That is why, for now, I keep an open mind and don't restrict myself to approved theories or certain ways of thinking.

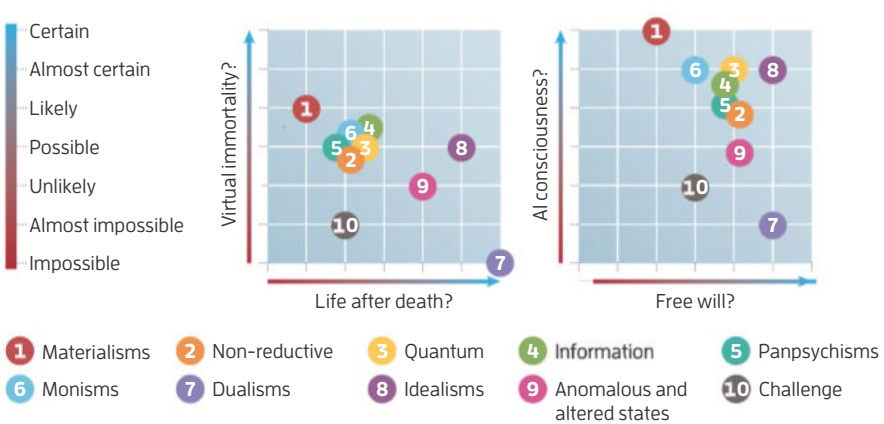
Finally, a confession: my lifelong pursuit of consciousness hasn't been entirely motivated by hard-nosed science or cool-coated philosophy. Ever since I was teenager, I have been haunted by a less-than-rational thought: "Should a being who can perceive eternity be denied it?"

But I won't fool myself. ▮

Robert Lawrence Kuhn is the creator and host of the TV series *Closer to Truth*, and the author/editor of the *Landscape of Consciousness* website

Existential implications of consciousness

Each category of consciousness has implications for several profound questions: can a digital clone of our minds achieve virtual immortality? Can our minds survive beyond death? Can artificial intelligence become conscious? And do we have free will?



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The back pages

The science of exercise

Better when we're together

When it comes to boosting mental health and even improving performance, group exercise comes out on top, finds **Grace Wade**

Grace Wade is a health reporter for *New Scientist* based in the US

GROWING up, I avoided team sports at all costs. Eye-hand coordination just isn't my strong suit. Plus, I have a pernicious competitive streak. Pair the two together and sport became a source of frustration rather than fun. But recent studies are making me rethink that attitude. It turns out that group exercise, especially team sports, may be better for our health than working out alone.

A 2023 analysis found that participating in sport, either recreationally or competitively, is linked with lower stress, less anxiety and better mental health, such as higher self-esteem. And these effects were especially pronounced in team sports. In fact, such sports seem to improve mental well-being more than other forms of exercise, regardless of the amount of physical activity.

The social aspect may also enhance sport's physical benefits. For one, exercising with others increases the likelihood of showing up to work out. In a 2024 study, more than 770 participants received a cash reward each day they visited the gym. But some of them also had to bring a friend to cash in. These people turned up about 35 per cent more frequently than those who could arrive alone. A follow-up survey suggested this was because a workout buddy increased accountability and made exercising more enjoyable.

Other research has revealed that this enjoyment might even improve performance. One study of people who took part in free communal runs found that those who did so with friends and family felt more energised, which, in turn, was linked to running faster. Research into competitive rowers, meanwhile, discovered that those who looked at a photo of a loved one while rowing could exercise for about 20 per cent longer than those staring at a stranger's photo.

RICH BOWEN PHOTOGRAPHY/ALAMY

While we don't know exactly why this is, it probably relates to how we process fatigue. It is our brain, not our muscles, that ultimately generates feelings of exhaustion. Fatigue is protective – it stops us from pushing beyond our physical limit and risking injury. So exercising with a buddy (or even just a photo of one) could signal to our brain that we are in a safe environment, allowing us to avoid fatigue for a bit longer.

This idea reflects a broader shift in exercise psychology. While this has focused on how competition boosts performance, more studies are now examining the influence of cooperation. After all, our greatest physical trait as a species – the ability to run long distances – is most likely to have evolved via group hunting. We are probably wired to work out with others.

I find this comforting. It has also helped me to focus on the cooperative aspect of sports, instead of their competitive side. I am running a half-marathon with my best friend soon and she has suggested we run side by side. I think that may be just what I need to help me cross the finish line. ▮

The science of exercise appears monthly

Next week
Dear David

These articles are posted each week at newscientist.com/maker

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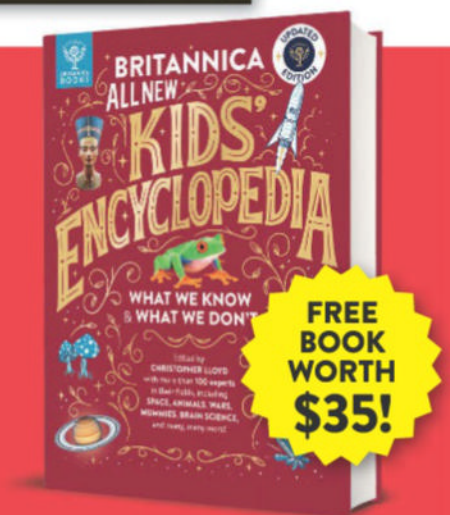
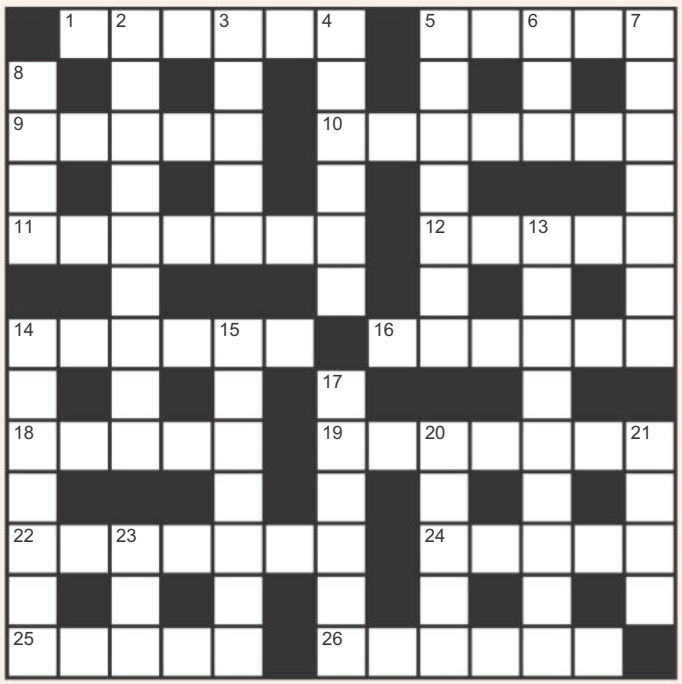


Cryptic crossword #173 *Set by Rasa*



Scribble zone

Answers and the next quick crossword next week

ACROSS

1 Finish invitation, taking hour (6)
5 Flees Karloff's monster features (5)
9 Oscar and eccentric dear had a row (5)
10 Give a darn about library quality (7)
11 Peg wears unfinished hat the wrong way, blushing deeply (4,3)
12 Bit of lacquer absorbed by masterly earthenware (5)
14 Live by own parent's admonishment (6)
16 Somewhere in Africa, a guy almost recalled mutating DNA (6)
18 Block nurses concerned with vision (5)
19 Saying part of speech after appearance of expert (7)
22 Our group primarily believes alternative to Google provides strong material (7)
24 Initially, evergreen tree abuts street (5)
25 Fleshy fruit languish at hearing (5)
26 Harangue one going into business (6)

DOWN

2 Oh, he's sore after breaking good luck charm (9)
3 Work essentially covers the German Chiroptera, for one (5)
4 Make secret fish, following directions on back of envelope (6)
5 Canine obsession: carrying tattered doll (7)
6 Testing facility left with blood type or two (3)
7 Museum showing mushroom's northward ranges (7)
8 Mummy's home with turkey breast starter (4)
13 Solitary daughter squeezes toothy thing like a rabbit (4-5)
14 King, maybe last of line, got married covered in sweat (7)
15 I do a makeover on cycling figure of myth (7)
17 Tap place disrupted by GI upset (6)
20 Put forward assassin? (5)
21 2 Down, 5 Down, 8 Down, 13 Down, and 15 Down try hanging upside-down? (4)
23 With temperature rising, save heat unit (3)

Our games are now solvable online
newscientist.com/games

Quick quiz #325
set by Tom Leslie

1 What is the name of Europe's oldest known natural mummy?

2 On 8 October, Susumu Kitagawa, Richard Robson and Omar Yaghi were awarded the Nobel prize in chemistry for their work on what?

3 Which physical constant is used to convert between the frequency and energy of a wave?

4 In late September, it was reported that researchers had made fertilisable egg cells using DNA from which other type of cell?

5 What name is commonly given to a phenomenon, recently tested in space, where a chain rises like a fountain as it falls out of a container?

Answers on page 47

BrainTwister
set by Christopher Dearlove
#96 Multiplying dice

I roll two standard six-sided dice, but instead of adding the values as usual, I multiply them. What is the average value of this product?

What is the probability of a result that is greater than the average value?

What is the probability of a greater-than-average result if I roll three dice instead of two dice?

Answers next week

Wrapping up

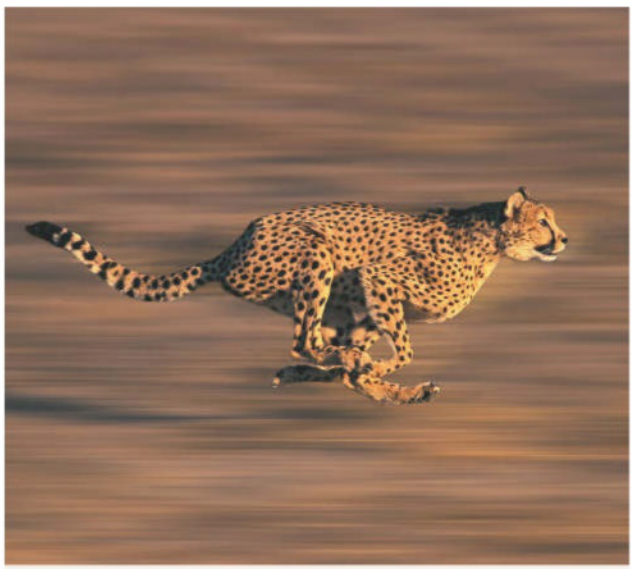
Should the bubbles on bubble wrap face the inside or the outside of the object?

Matthew Stevens
Sydney, Australia
The bubbles should face the object being wrapped. Placing the flat face of the plastic on the outside protects the entire surface of the object from impact. Placing the bubbly side on the outside leaves the channels between the bubbles unprotected from pointy objects. And if the aim is to provide thermal insulation, the bubbles must still face inside, as the flat side minimises the surface area through which heat can be lost or gained, insulating the entire object, not just the parts covered by the bubbles.

Sam Edge
Ringwood, Hampshire, UK
Assuming the bubble wrap isn't going inside the object, usually it is better to encase the fragile object so that the smooth side of the bubble wrap is outermost, as this reduces both friction when putting it into any containing box and the risk of sudden shocks caused by the bubbles snagging in transit. If the object itself isn't smooth, this also allows the bubbles to deform into the irregularities.

"Bubble wrap facing the inside is less likely to get popped in transit, so the recipient has the satisfaction of bursting it"

Carol Stevenson
London, UK
When wrapping ceramics, I have been taught to keep the bubbles facing inwards, towards the work, because that way they are protecting the contents. The bubbles are also less likely to get popped in transit, so the recipient has the satisfaction of sitting down and bursting them!



SHUTTERSTOCK/SLOWMOTIONGLI

Are there limits to evolution, or could a cheetah evolve to run even faster?

This week's new questions

Push it to the limit **Can eagles have sharper eyes? Or cheetahs run even faster? Or must the evolution of any adapted trait in nature reach a limit? *Jim Wegryn**, Dimondale, Michigan, US*

What's the matter? **If an antimatter comet or meteor came into our solar system, how would we know? What if it hit Earth? Gary Golding**, *Robertson, New South Wales, Australia*

Cloud colour

Why do rainbows refract light into several different colours, but we don't see the same effect with cloud inversions?

Mike Follows
Sutton Coldfield, West Midlands, UK
The formation of a rainbow requires the observer to be between the sun and falling rain, with the rain in front and the sun behind. Sunlight passes from behind the observer, refracts as it enters each raindrop, reflects off the back surface, and then refracts again on its way back to the viewer. The raindrops need to be relatively uniform in size and well separated. In contrast, the water droplets in a cloud are typically less uniform and more densely packed. Even if light undergoes the refraction-reflection-refraction process required for rainbow formation, it is scattered multiple times before it can reach the observer. This is why clouds appear opaque.

In inversion conditions, the temperature increases with altitude, rather than decreasing as it usually does. This allows people at a high vantage point to look down on fog or low stratus clouds. The suspended water droplets in the fog or clouds are typically 10 to 100 times smaller in diameter than raindrops, making them light enough to remain airborne and not fall as precipitation. At this droplet size, diffraction becomes more dominant than refraction. Each droplet creates its own diffraction pattern, consisting of alternating bands of constructive and destructive interference for each wavelength of light. As the droplets get smaller, these bands broaden. When the droplets are tiny enough, the interference bands from different colours spread out so much that they overlap, mixing the colours and producing a white arc.

A Brocken spectre is the shadow of an observer cast onto cloud or mist. It is often surrounded by a glory, which is centred on the shadow and results from the backscatter of sunlight, resembling a halo or colourful ring. A glory forms when the cloud or fog consists of uniformly sized water droplets, typically between 5 and 20 micrometres across. The physics is quite complex but intriguingly, can be explained using either classical or quantum models. The smaller the droplets, the larger the glory appears, though its colours tend to be less intense.

Staying warm

When getting dressed in the morning, I want to warm up as quickly as possible. Should I put on my trousers or top first? (continued)

Peter Bursztyn
Barrie, Ontario, Canada
Our body has two broad temperature regulation regions: the core and the periphery. The core is the trunk and its organs, plus the brain. The periphery is everything else: limbs and their muscles, plus the skin.

Our core temperature is actively regulated, maintained close to 37°C (98.6°F). It rises perhaps 2°C (3.6°F) during strenuous exercise, and falls slightly at night.

One method our body uses to regulate its core temperature is to alter the flow of blood to the periphery. More blood is sent to the skin when we are trying to get rid of heat, less if we are conserving heat. In the limbs, we have the option of sending blood

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Tom Gauld
for New Scientist

back to the heart either by surface veins, or by veins lying close to arteries feeding that area. In the latter case, returning venous blood is warmed by arterial blood flowing towards the periphery.

It is probably advantageous for you to don your top first, because the skin covering this area tends to be warmer than that covering your legs. Also, the hair on your legs (typically more hirsute than your arms) helps to insulate them.

However, the advantage is very small, particularly as there will be just a minute or two before your trousers are on, too!

Pauline Keyne
Beaconsfield, Buckinghamshire, UK
The assumption behind this question is that the requirement relates to a cold morning. This answer is: top first, with socks next. This is not empirically based, but is peer reviewed. I'll leave it to other respondents to tackle the biophysics.

Whenever I am already dressed and cold I put on an extra layer.

"The advantage of putting your top on first is small, as there will be just a minute or two before your trousers are on, too"

Hikers carry an extra jacket or fleece in case of needing to warm up, but generally only waterproof over-trousers in the event of rain. It is very common, when feeling cold, to pull sleeves down to cover wrists. Adding a scarf or other form of neck warmer is often sufficient to feel cozy. Some (many) years ago, when the bedroom windows were frosted over (yes, that long ago), I can remember my granny telling me about getting dressed in bed. That was definitely best done "top first" as the arms and shoulders were likely to become exposed when struggling to put the rest on. This method avoided getting cold before warming up, so I would recommend it to the questioner.

Finally, I would surmise from the question that the option of heating the room to the extent that there is no need to know how best to warm up has been rejected. The questioner is therefore doing their bit to reduce carbon emissions, which surely carries with it a warm glow.

Krishnan Sriram
Chicago, Illinois, US
The answer is easy based on anatomy and physiology. The rule of 9 is used often in assessing areas affected by burns, which splits the body into 11 areas of 9 per cent each. The perception of cold depends on the skin surface exposed. If we wear long-sleeved tops, the area we will cover to prevent heat loss would be 9 per cent for each arm, and 18 per cent each for the anterior (front) and posterior (back) torso, which totals 54 per cent of the body's surface area. Compare this with the area covered by wearing trousers, which is 18 per cent for each leg, totalling 36 per cent. Most of us would subjectively experience better warming by wearing tops first. ▮

Answers

Quick quiz #325 *Answer*

1 Ötzi the Iceman
2 Metal-organic frameworks
3 The Planck constant
4 Skin cells
5 The Mould effect

Quick crossword #194 *Answers*

ACROSS 1 Great, **4** Crosshead, **9** Globule, **10** Airship, **11** Navel, **13** Treen, **15** Nth, **16** iOS, **17** Moore, **19** Belch, **21** Mouth, **23** *Akira*, **24** Via, **25** Two, **26** Opium, **28** Strep, **29** Bromine, **31** Calcium, **33** Amyl group, **34** Doors

DOWN 1 Gigantism, **2** Evolves, **3** Tau, **4** Chert, **5** Ova, **6** Siren, **7** Ethanol, **8** Depth, **12** Lymph, **14** Elemi, **18** Okapi, **19** Brass, **20** Heat pumps, **22** Ufology, **24** Vertigo, **25** Tibia, **26** O-ring, **27** Mocap, **30** Ego, **32** LSD

#95 Coin roll *Solution*

We assume the coin's centre is equally likely to land anywhere. If it settles more than 0.5 cm from a line, we win. The chance of this is the distance between lines minus 0.5 cm on each side, divided by the total distance (W). This gives (W – 1)/W. So, for a 50 per cent chance of winning, W = 2 cm. On a square grid, the coin won't touch an edge if its centre lies in a square whose edges are 0.5 cm within the grid square. The proportion of each grid square of side length W taken up by this is $(W - 1)^2/W^2$, which leads to W ≈ 3.41 cm. For a grid of equilateral triangles, by similar calculations, the chance of winning is $(W - \sqrt{3})^2/W^2$. So W ≈ 5.91 cm for a 50 per cent chance to win.

Speaking our truth

The experienced science journalist soon learns to skim over certain sections of scientific papers: specifically, the sentences stating that the research represents "a significant advance" and "expands our understanding". Not because they're incorrect, but because literally any study that achieves anything at all can make these claims, and academics are incentivised (as we all are) to amplify the impact of their work.

Except for the times when they don't bother. Via a long sequence of events that started with reporter Matthew Sparkes and went via the social network Bluesky, Feedback discovered a paper on the arXiv preprint server from 2018 that should win a prize for its absolute refusal to make any big claims.

In it, researchers Joseph Redmon and Ali Farhadi described their latest iteration of YOLO: one of those AI systems that can be trained to recognise objects in images. YOLO can beat those CAPTCHA tests that ask you to click all the squares that contain bicycles, and it has been used to spot smuggling ships. All of which is quite impressive/alarming (delete as appropriate), but by 2018 the pair were evidently coasting.

It starts with the paper's title: "YOLOv3: An incremental improvement". The short summary continues the trend by claiming: "We made a bunch of little design changes to make it better." The main text begins: "Sometimes you just kinda phone it in for a year, you know? I didn't do a whole lot of research this year. Spent a lot of time on Twitter." That last line certainly dates the paper.

The authors go on to explain that they "mostly took good ideas from other people" to improve YOLO. They describe this in some detail, after first admitting that the tweaks are "honestly, nothing like super interesting, just a bunch of small changes that make it better".

Then we get to section 4, which is titled "Things we tried that didn't work". Feedback thinks this should be included in all scientific papers as a matter of course. It would save other researchers so much time.

The authors confess that they have only described "the stuff we can remember", but they do recall that they tried adding something called "focal loss", and that it made the model less accurate. "YOLOv3 may already be robust to the problem focal loss is trying to solve," they say, "because it has separate objectness predictions and conditional class predictions. Thus for most examples there is no loss from the class predictions? Or something? We aren't totally sure."

Feedback can't quite believe we missed this in 2018, or when it was picked up on the aggregator site Reddit in 2024. But we are grateful to sociologist Per Engzell, who said on Bluesky that "Limitations sections are where academics practice radical honesty for exactly one paragraph", and to data scientist Johan Ugander, who replied that the YOLOv3 paper should get an award for "most honest paper".

Surely, someone must know of an academic being even more disarmingly honest about how little they have accomplished. Emails to the usual address.

Twisteddoodles *for New Scientist*

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Consideration of items sent in the post will be delayed

A long-lived bit

"I know you are avoiding nominative determinism," writes Clare Boyes, incorrectly, "but couldn't resist sending you this one which came in an email today from the British Wildlife Newsletter." It was a book called *Tree Hunting: 1,000 trees to find in Britain and Ireland's towns and cities* by Paul Wood.

Likewise, Robert Masta points out that our recent special issue on "how to live to 100" (TL;DR don't die) featured a longevity researcher named Paul Lazarus.

Sleep on this

Back in the mists of time (July), Feedback wrote about receiving a press release that staunchly defended the environmental sustainability of avocados, only to discover that it came from the World Avocado Organisation. We concluded that these people might be right or might be wrong, but, either way, they may have been operating in an incentive structure.

We haven't heard anything further from the avocadomongers, but we did get a series of press releases about the importance of sleep. "Can't find a solution? Science confirms that sleeping on it really does solve problems" announced the first. It went on to share "a fascinating new research" explaining that "the old advice to 'sleep on it' might actually be one of the smartest problem-solving tools we have".

This is because the brain continues processing memories and forming new connections while we sleep, it explains, sometimes generating new insights by fusing new and old ideas. There's talk of "memory consolidation", "the prefrontal cortex (the brain's inner critic)" and "associative thinking".

A follow-up email went further, with a dramatic and grammatical title: "New study shows rising youth deaths and could worsen if sleep deprivation persists, experts warn". The press release linked poor sleep to chronic health conditions. It also featured a quote from a "Certified Sleep Coach", which may well be a real thing, but in our addled mind it generated an image of a sweaty man in a tracksuit, blowing a whistle and yelling at us to "give me seven [hours]!" Still, the message was clear: sleep good.

Possibly the foreshadowing at the start gave it away, but in case you hadn't guessed, both emails were sent on behalf of Amerisleep, which is, of course, a supplier of mattresses.

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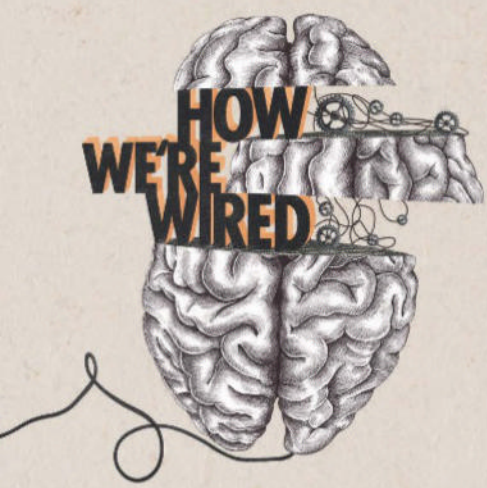

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