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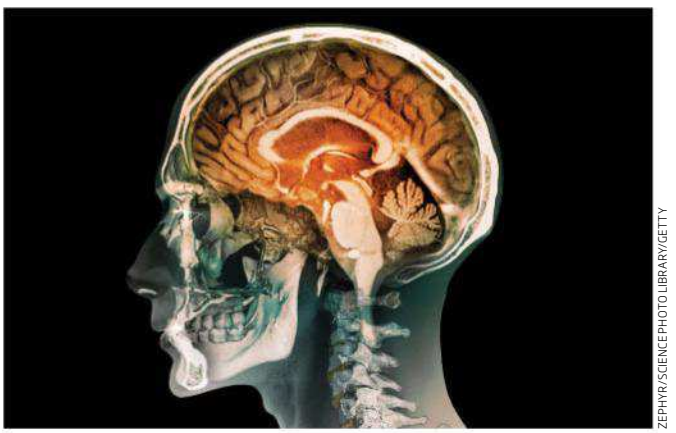

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MARTIN H. SIMON/REDUX / EYEVINE

Protest and survive

This year's March for Science needs to be even bigger

WHAT a difference a year makes. In April 2017, people across the world took to the streets to show their support for science in the face of what appeared to be an existential threat. Fuelled by anger and dismay at the election of Donald Trump as US president, the March for Science began life as an online discussion group, but it quickly snowballed into a global protest: on the day itself more than a million people turned out in more than 600 cities worldwide.

At the time, Trump looked like a major threat to science funding and the scientific world view, with attacks on environmental science sitting front and centre and other anti-science impulses waiting in the wings.

A year on, this concern appears unexpectedly overblown. Trump remains hostile to science but has also proved to be an ineffectual president, largely incapable of inflicting any severe damage. Last month he reluctantly signed a federal spending bill that the journal *Science* described as "the largest US research spending increase in a decade". Among the bodies that received increases to their budget were NASA, the National Science Foundation, the National Oceanic and Atmospheric Administration, the US Geological Survey and the National Institute of Standards and Technology. Even the Environmental Protection Agency avoided the anticipated deep cuts.

Trump didn't personally support any of these measures, but lacked the political capital to push his own agenda through.

The March for Science movement has claimed some of the credit for this unexpected win, telling its supporters "You Sent a Clear Message to Congress – and They Listened!"

"Getting more than a million marchers last year was a major achievement, but it set the bar very high"

For a movement committed to scientific objectivity – it famously used crowd science techniques to estimate the turnout last year, for example – that seems like an unsubstantiated claim. But credit where it is due: March for Science isn't just about turning up to a protest once a year. It is also developing into an effective grassroots lobbying operation (see page 24). In January it encouraged its US supporters to email their representatives in Congress urging them to resist the president's proposed science budget cuts. Congress resisted. It is tempting to join the dots.

But by its very nature, lobbying is a behind-the-scenes activity. Movements for social change only succeed if they have mass grassroots support, and also the appearance of mass grassroots support. That is why this year's March For Science – due to take place on 14 April in cities worldwide – is even more important than last year's.

Getting more than a million marchers last year was a major achievement, but it sets the bar very high. This year's protest needs to be as big or preferably bigger, lest the news media ignore it or opponents claim the movement is fizzling out.

If you support science and rational policy, please consider taking part. Trump's guns may have been spiked for now, but he is still in power and far from the only science-unfriendly leader in the world. Last year showed that science really can do politics. Now it is time to make history too. ■

Memory code cracked

Gene patterns in the brain provide a new window into the mind

Jessica Hamzelou

MEMORIES have a unique genetic signature in the brain – a code that has only just been discovered and unlocked. The findings, in mice, suggest we may be able to read people's memories by examining the patterns in their brains, and even one day alter or repair them to treat psychiatric disorders or memory loss.

The brain seems to store memories in new connections between neurons. To do this, the neurons need to make new proteins – a process that is thought to be controlled by hundreds of genes.

While investigating how this works, Ami Citri at the Hebrew University in Jerusalem and his colleagues discovered that particular experiences – be it an electric shock or a hit of cocaine – elicit different changes in gene activity in the brains of mice.

These mice were given a variety of positive or negative experiences, such as electric shocks to their feet, a sugar treat, a dose of a chemical that makes them feel ill or cocaine. An hour later, they were euthanised and the team looked at which genes were being expressed in seven areas of the brain that are involved in memory, including the hippocampus and amygdala.

"If we can identify what's necessary to make a memory, we could help restore damaged ones"

Citri was surprised to find that all of the mice given cocaine, for example, showed the same general pattern of gene activity. The patterns were so clear that the team could guess what experience a mouse had been through with over 90 per cent accuracy just by analysing the levels of activity of different genes in their brains (*eLife*, doi.org/cm6w).

While each experience had its own pattern, the signatures of the more positive experiences were relatively similar to each other, as were the negative ones, suggesting that bad memories and good memories are recorded differently.

Previous events also had an effect. The memory of a dose of sugar had a different signature if it was a mouse's first taste, or if it had already developed a sugar habit. "It's very nuanced – we can separate out a wide variety of different experiences," says Citri. "Each memory that's being encoded has a unique input in the brain in terms of the genes switched on to encode it."

The pattern of gene activity seems to peak about an hour after the experience has taken place, says Citri. Amy Milton at the University of Cambridge says that human memory probably works in a similar way because we use the same mechanisms to form memories. "It's potentially exciting," she says.

Citri hopes it will be possible to detect genetic memory signatures in blood samples, so that researchers can read this code in live animals or people. He says his team has had promising early results doing this in mice. If it works, it may help us understand how people can experience the same event in different ways. "People who are more resilient might encode memories differently," says Milton.

As well as a peak in gene activity soon after going through an experience, Citri thinks that more subtle, permanent marks may be laid down on genes too. These epigenetic signatures might reveal something about the experiences in a person's more distant past, says Citri, although he has not yet studied this.

Genetic signatures that reveal a person's subjective experiences could give doctors deeper insights

GETTY

Cleaner air really benefits kids

CHILDREN benefit from even a small reduction in air pollution. The finding suggests that efforts to tackle air pollution really can make a difference.

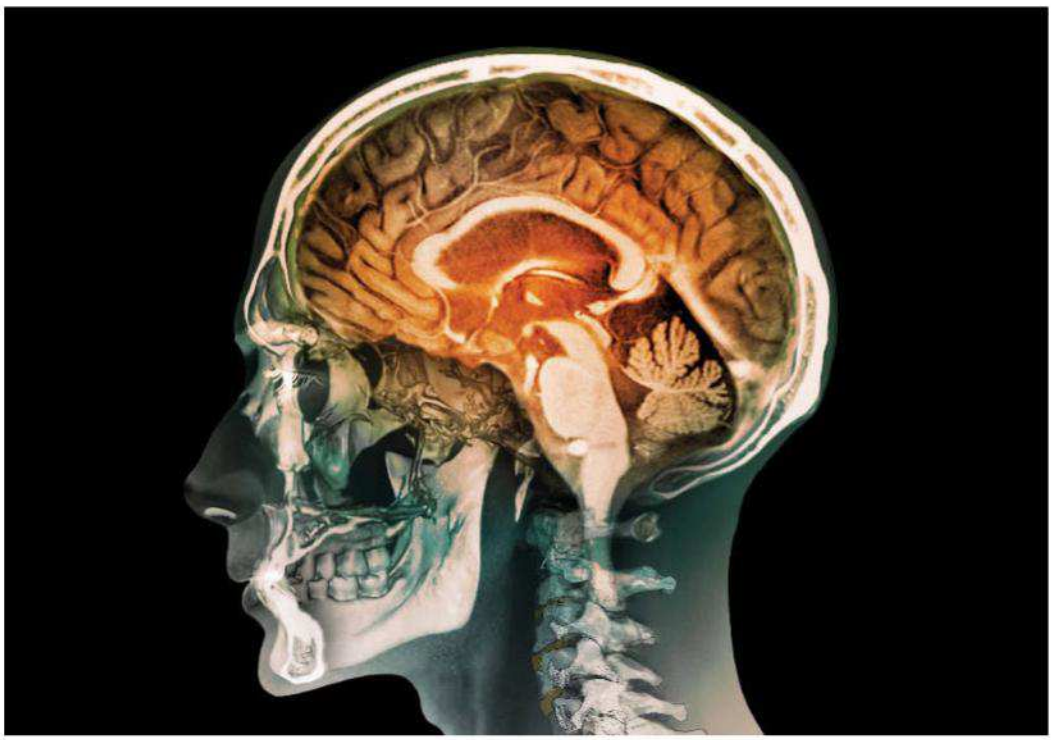
In 2007, levels of air pollution in the city of Stockholm in Sweden fell by about 5 to 15 per cent after it introduced a congestion charge. This small reduction seems to have halved the number of children admitted to hospital with asthma attacks, from 18.7 kids per 10,000 to 8.7 per 10,000, according to a study by Emilia Simeonova of Johns Hopkins University in Maryland (*National Bureau of Economic Research*, doi.org/cm2d).

However, congestion charges alone do not necessarily reduce air pollution. In London, nitrogen dioxide levels rose by around 10 per cent in the four years after a similar congestion charge was introduced in 2003, according to findings presented last month at a meeting of the Royal Economic Society in the UK. This may have been due to a rise in the proportion of diesel vehicles. The city plans to introduce tougher measures.

Online equality and privacy in trouble

THE latest annual Internet Health Report by Mozilla, the organisation behind the Firefox web browser, says the web is in a bad way when it comes to online equality and privacy.

Around half of the world's



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into conditions like post-traumatic stress disorder, and possibly even lead to new treatments that alter memories.

Current therapies teach people with traumatic memories and phobias to change how they respond to them, but this can involve prolonged periods reliving a painful memory. A one-off treatment to change a memory's genetic signature from a negative pattern to a positive pattern could be a better way.

Citri and his team have managed to do this in mice. They were able to change a mouse's memory of an electric shock by injecting it afterwards with a gene that is involved in memory formation. The mouse no longer froze with fear when the memory was retriggered, says Citri.

How an experience is encoded can reveal if it's good or bad

The memory code could even have forensic applications in the future, revealing the most recent experiences of someone who has been killed. "It's a fascinating proposal," says Clea Warburton at the University of Bristol, UK.

For example, it might one day be possible to look at a brain region linked to recognition, and be able to tell whether a murder victim had seen someone they knew before they died. "But you would have to get in there extremely quickly, as proteins start to degrade within minutes of death," says Warburton. "It probably wouldn't give you more information than a good forensic scientist could, but I wouldn't be surprised if we end up with a film about this."

Understanding and treating memory loss may be a better application of the findings, says Warburton. "If we can identify the brain regions and proteins necessary for memory formation, we can go in and manipulate the neurons," she says. "Then when people have brain damage, we could help restore memory." ■

population now has internet access, but there is a stark geographical divide. Nearly 80 per cent of people in Europe are online, while in Africa the figure is just 20 per cent.

Men outnumber women online in every region except the Americas. In Africa, there are three women online for every four men, a gap that has widened since 2013.

Two-thirds of internet users live in countries that regularly censor the internet. WhatsApp, the most commonly used encrypted chat app, was blocked or throttled in 12 out of 65 countries examined by the report.

Last year also saw a concentration of big tech power. Facebook added over a billion users across its different platforms, including WhatsApp and Instagram, while over 90 per cent of all web searches are done on Google.

Over-the-phone abortion service

THE world's first phone-based abortion service has been found to be safe, effective and convenient.

Since 2015, women in Australia have been able to order abortion pills from a private provider, the Tabbot Foundation. After a woman requests the pills, a doctor calls her for a health check and to organise tests to confirm she is less than nine weeks pregnant. Then, a package of drugs is posted to her, and a nurse calls to explain how to take them. There is a 24-hour support hotline, and the nurse calls again later.

A study of the first 1000 women who used the service shows that over 95 per cent had an abortion at home with no complications, and no need to see a doctor afterwards (*Australian and New Zealand Journal of Obstetrics and Gynaecology*, doi.org/cm7q).

Two-thirds of Tabbot's clients were from rural areas. "It means they don't have to travel long distances or face possible judgement from the one doctor or pharmacist in their town," says Paul Hyland, who set up the foundation.

Syrian chemical weapons attack

INTERNATIONAL tensions have rocketed after a chemical attack in Syria killed at least 42 people on 7 April. Reports of victims with burning eyes and breathing problems suggest helicopters dumped chlorine bombs on the town of Douma, near Damascus. The Organisation for the Prohibition of Chemical Weapons (OPCW) is investigating.

Syria signed the international treaty banning chemical weapons in 2013, under pressure from the US and Russia, after it attacked civilians with the nerve gas sarin. The OPCW says it destroyed 94 per cent of Syria's banned chemical weapons by 2014. Since then, Syria has repeatedly bombed civilians with chlorine, a chemical not banned by the treaty unless used as a weapon.

In April 2017, it also attacked three villages with sarin. Russia denied Syria was behind that attack, but the US retaliated by bombing a Syrian airfield. After having reacted to the sarin attack, the US is under pressure to issue a military response again.

The long and winding history of the Nile

THE source of the Nile river remained a mystery to Europeans for thousands of years. Now another puzzle has finally been solved: the source of the river in deep time.

The Nile had become a major river by around 31 million years ago, reports the first team of geologists to put a firm date on its origin. "The Nile's the longest river in the world, and being able to figure out when it started is, for me, really exciting," says Yani Najman at Lancaster University, UK, who led the team.

Rivers carry sediment from their source down to the sea. So comparing the minerals in a river's sediment deposits with the rocks found upstream reveals where its waters started out from in the past.

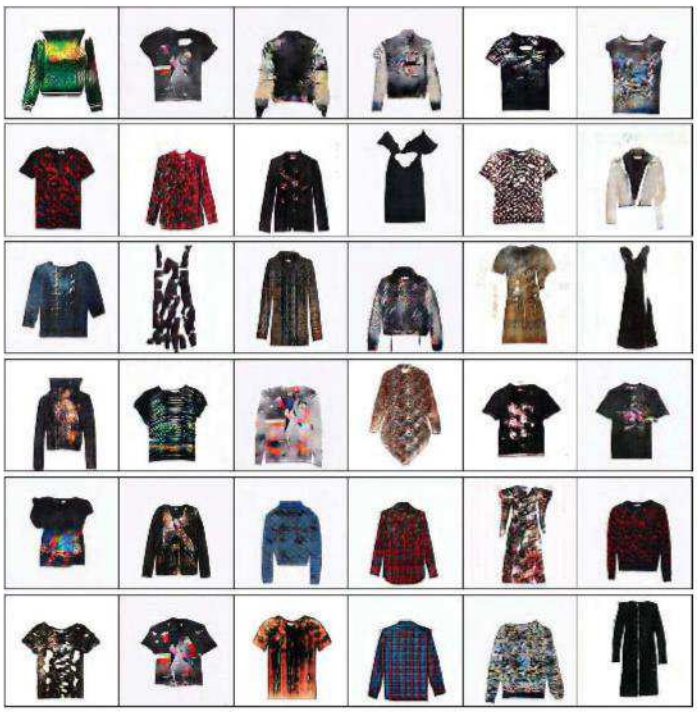
The Nile's story has remained elusive because its most ancient deposits are buried beneath thousands of metres of Nile delta sediment, says Najman. Only oil companies have drilled to such depths in the area and they don't like to share their findings.

But after years of negotiation, BP Egypt provided samples from delta sediments dated to about 31 million years ago. These contain minerals matching those in rocks in the Ethiopian Highlands – the place where one major branch of the river, the Blue Nile, gets going (*Earth and Planetary Science Letters*, doi.org/cm7r).

That means the Nile was already flowing all the way from Ethiopia to the Mediterranean at least 31 million years ago. That is much older than some previous estimates.

Studying the Nile's origin is also revealing the geological history of the entire region. The findings mean the Ethiopian Highlands must have been uplifted around this time, too.

"If you're going to study rivers, you should look at them in their entirety," says geomorphologist Martin Williams at the University of Adelaide in Australia. And that, he adds, is what Najman and her team did. Lucas Joel ■



OTHMAN SBAI, MOHAMED ELHOSEINY, ANTOINE BORDES, YANN LECUN AND CAMILLE COUPRIE

The latest collection from upcoming designer StyleGAN

Facebook's AI fashion designer

Richard Kemeny

COCO CHANEL had it. Yves Saint Laurent, too. And Gianni Versace without doubt. Originality put these designers into the fashion history books. A team at Facebook hopes to use artificial intelligence to take fashion in bold new directions as well.

Previous AIs have created music, artworks and poetry. Now the Facebook researchers have coaxed three AIs into designing clothing. Overall, they produced around 1000 items, including handbags, jumpers and T-shirts. The aim was to come up with truly original creations that could then inspire human designers.

"Technology can amplify our creativity," says Camille Couprie at Facebook's AI research lab in Paris. "It can take a lot of brain power to think about new ideas, so if AI can help with that and accelerate that process it would be good."

The team has been talking with a well-known fashion brand about tapping into the method, but the resulting images are currently too small to be useful for a real-world fashion house.

The designs were produced by algorithms known as generative adversarial networks (GANs).

"One of the AIs had the strange idea of creating some trousers with an extra pair of legs"

These AIs pit two neural networks against each other, one generating ideas, the other judging them. Through thousands, and sometimes millions, of iterations, both sides master their skills. Eventually, something is created that suitably satisfies both the AIs and humans.

But GANs usually produce close imitations of the images they were trained on. True originality, as many fashion connoisseurs would agree, is trickier. To inspire a more creative edge, the team introduced two disruptive functions, which they termed "creativity losses", into the networks. In essence, these confused the AIs enough that they were forced to deviate from existing styles and towards more original content.

Three GANs were trained on around 4000 images of existing fashion items created by humans, learning the importance of texture and shape. Two were off-the-shelf GANs. The third, dubbed StyleGAN, was constrained in the shapes it created so the fashion items would actually be wearable. However, it was given carte blanche on other design elements.

To judge how the AIs had done, the team showed 800 of the images to people for them to review. Almost two-thirds of the designs were judged as being created by humans, and they were mostly considered original too. StyleGAN had the best eye for fashion as rated by the reviewers (arxiv.org/abs/1804.00921).

However, certain designs were a little too novel. For example, one of the AIs had the strange idea of creating some trousers with an extra pair of legs.

It is unsurprising that algorithms can design clothes just as well as humans, says Stevan Harnad at the University of Quebec in Montreal, Canada. But he wonders whether people might eventually become bored of AI designs. "The human behavioural side of this study did not get far enough to see whether human observers would eventually have detected something mechanical and repetitive in the designs," he says. ■

Child cognition shaped by pregnancy infections

THE brain function of infants may be boosted or hindered by infections experienced by their mothers during pregnancy.

The finding makes it all the more important that pregnant women get vaccinated against flu and practise basic hygiene measures like hand-washing, says Bradley Peterson of the Children's Hospital Los Angeles.

Some microbes can directly infect a fetus during pregnancy and cause developmental problems. One example is Zika virus, which appears to infect fetal brain cells. But there is some evidence that maternal infections might also affect fetuses indirectly, by putting the woman into a state of heightened immune system activity.

A higher rate of schizophrenia has been detected among people who were born soon after the 1957 global flu epidemic, for instance. Other studies suggest flu may raise the chances of having a child who has schizophrenia from around 1 per cent up to as much as 7 per cent. Infections have also been linked to autism, attention deficit hyperactivity disorder and depression.

But these studies aren't conclusive and there has been debate about whether inflammation during pregnancy really does affect children's brains.

To get a clearer picture, Damien Fair of Oregon Health & Science University in Portland and his colleagues followed 46 women from pregnancy through to early motherhood. During pregnancy, they monitored the women's blood for signs of inflammation. Two years after birth, the researchers assessed the women's children using a memory game in which they had to remember where stickers were hidden. The team found that infants who performed worse at the test had been born to women who showed signs of high inflammation during pregnancy.

Looking back to brain scans taken when the children were 4 weeks old, the team saw that those whose mothers had had higher inflammation during pregnancy had different patterns of connections between several parts of the brain involved in memory. This included a system that is involved in paying attention to important things, known as the salience network (*Nature Neuroscience*, DOI: 10.1038/s41593-018-0128-y).

Inflammation during pregnancy can affect cognitive ability later on

VOLKER OTTEN/GETTY

But the picture isn't clear-cut. Peterson's group recently did a similar study, in which they followed 21 pregnant teenagers and their babies. While they also found that higher inflammation in pregnancy was linked with altered brain connections in the salience network at a few weeks of age, this didn't seem to have a bad effect. When tested at the age of 1, these infants actually had better cognitive abilities than those whose mothers had had less inflammation during pregnancy.

That might be because the fetal brain tries to compensate for the damage caused by inflammation in a way that strengthens some cognitive abilities, says Peterson. "If there's a problem in one part of the system, other portions kick in to try to right the ship," he says.

As well as getting vaccinated against flu and practising good hygiene, Peterson suggests that pregnant women may want to wear face masks if they need to spend time with someone who has a contagious illness. **Clare Wilson** ■

Robots aren't coming for your job after all

ROBOTS are the great bogeymen of the 21st century. With their superhuman strength and non-stop work ethic, many feel they are gunning for our jobs. But these fears may be overblown. The first comprehensive look at automation on the German economy suggests that robots created more jobs than they destroyed.

People's fears have been stoked by headlines warning of the robot takeover. A 2013 study by the University of Oxford, for example, suggested robots are set to replace as much as 47 per cent of the US workforce and 35 per cent of the UK's.

But far from this apocalyptic scenario, automation resulted in an overall increase in jobs of between 1.5 and 1.8 per cent in Germany between 2011 and 2016. While robots claimed 5 per cent of jobs, more new ones were created. What's more, most of these tended to pay better than those that had been lost.

An industrial robot may replace 100 workers, but there are knock-on effects that can add jobs elsewhere. "Now the company can produce the same good, but more cheaply. Demand goes up and they need to hire more people to fill the new demand," says Melanie Arntz at the Centre for European Economic Research in Mannheim, Germany. The same effect should be seen in other countries, including the UK and US, she says.

"An industrial robot may replace 100 workers, but knock-on effects can add jobs elsewhere"

Previous studies also overestimated the relationship between jobs that can be automated and those that will, says Arntz.

To come to this conclusion, Arntz and her colleagues surveyed 2000 senior managers at companies representing a broad swathe of the German economy. The researchers asked the managers to rate the level of automation at their companies in each year between 2011 and 2016. They then used data from the German Federal Employment Agency on around 300,000 workers to get the overall picture. Sally Adee ■

Sticky, slippery material pulls fog from the air

IN ARID regions, fog catchers can provide much needed water for drinking or crops. That process is now more efficient thanks to a material that encourages the build-up of larger droplets that slide off easily to be collected.

Water harvesting materials usually work by trapping droplets or helping them travel into a reservoir efficiently – they don't do both. That is because a material must be sticky to grab droplets, but slippery to let them slide into a receptacle. Most set-ups use vertical hydrophobic surfaces, on which some droplets – but not many – condense until gravity pulls them into a basin.

Tak-Sing Wong at Pennsylvania State University and his colleagues have now designed a material that is 200 per cent more efficient at harvesting water from fog. The surface chemically bonds with water molecules to collect more drops (*Science Advances*, DOI: 10.1126/sciadv.aaq0919).

To make it, they carved grooves 20 micrometres deep and 50 micrometres wide into a silicon sheet to give a larger surface area for water molecules to attach to. The sheet was coated with a liquid hydrophilic lubricant to which water can bond. As it is a liquid its molecules are always moving, so these bonds aren't permanent, as they would be if it were a hydrophilic solid. This makes the droplets stick to the surface while allowing them to slide around and coalesce into larger drops and finally be pulled downward off the vertical surface by gravity into a receptacle.

The researchers tested their material in a room with a commercial humidifier for two weeks. They found that a square metre of it could collect more than 100 litres of water per day. "For typical fog-harvesting mats that people use in remote areas, they can only collect around 1 to 10 litres of water per square metre per day. This is way better," says Wong. Leah Crane ■

MICHAEL PETRAGLIA

Al Wusta in Saudi Arabia, where the finger was found, once held lakes

Finger points to earlier Africa exit

Andy Coghlan

A SINGLE finger bone found in the Saudi Arabian desert is helping to rewrite the story of when and how modern humans left Africa.

Huw Groucutt at the University of Oxford and his colleagues found the finger bone at a site called Al Wusta in what is now the Nefud desert. It is the second bone in from the fingertip.

The team recognised the bone as human, and have now confirmed this by comparing it to finger bones of humans, extinct hominins such as Neanderthals, and other primates. Radiometric dating of the bone shows it is at least 85,000 years old (*Nature Ecology & Evolution*, DOI: 10.1038/s41559-018-0518-2).

This challenges the mainstream view, which is that our species left Africa only around 70,000 years ago, and then spread rapidly across Asia and Europe. This has looked increasingly shaky due to a series of finds in the Levant, the area east of the Mediterranean that includes Israel and Syria. In January this year, for instance, a team unveiled a human jawbone found in Israel that was 177,000 years old.

Despite such finds, many archaeologists still think humans didn't travel beyond the Levant until 70,000 years ago. Older artefacts and fossils have been found in Asia – but in all cases, people have questioned either the dating or whether the remains came from modern humans.

Six different views of the 85,000-year-old finger bone

IAN CARTWRIGHT

Because of this uncertainty, the Al Wusta finger bone is the oldest confirmed remnant of a modern human found outside Africa and the Levant. It adds to the evidence that our ancestors progressed beyond the Levant earlier than thought, creating a new staging post in what is now Saudi Arabia from which they could push into the rest of Asia.

"It now seems likely that early modern humans were in southern China 100,000 years ago"

"It now seems likely that early modern humans were in southern China about 100,000 years ago," says Chris Stringer of the Natural History Museum in London, UK.

Arabia was very different 85,000 years ago. The climate was much wetter, and the Al Wusta site was a mix of rich grassland and lakes. The most common animal bones found by the team were water-loving animals like hippos and buffalo.

The team also found 380 stone tools, suggesting that lots of our ancestors lived around the lakes. "These were bands of hunter-gatherers, and they would have been living on the edge of lakes – but mobile, hunting for animals and gathering plants, perhaps existing off some aquatic resources," says co-author Michael Petraglia of the Max Planck Institute for the Science of Human History in Jena, Germany.

Another intriguing question is whether the early humans of the Levant and Arabia all belonged to the same population, or whether they represent multiple migrations out of Africa.

"The Al Wusta research adds support to the notion that there were numerous, perhaps nearly continuous, pulses of *Homo sapiens* dispersals from Africa," says Donald Henry of the University of Tulsa in Oklahoma. ■

Entries for $250,000 Ryman Prize now open

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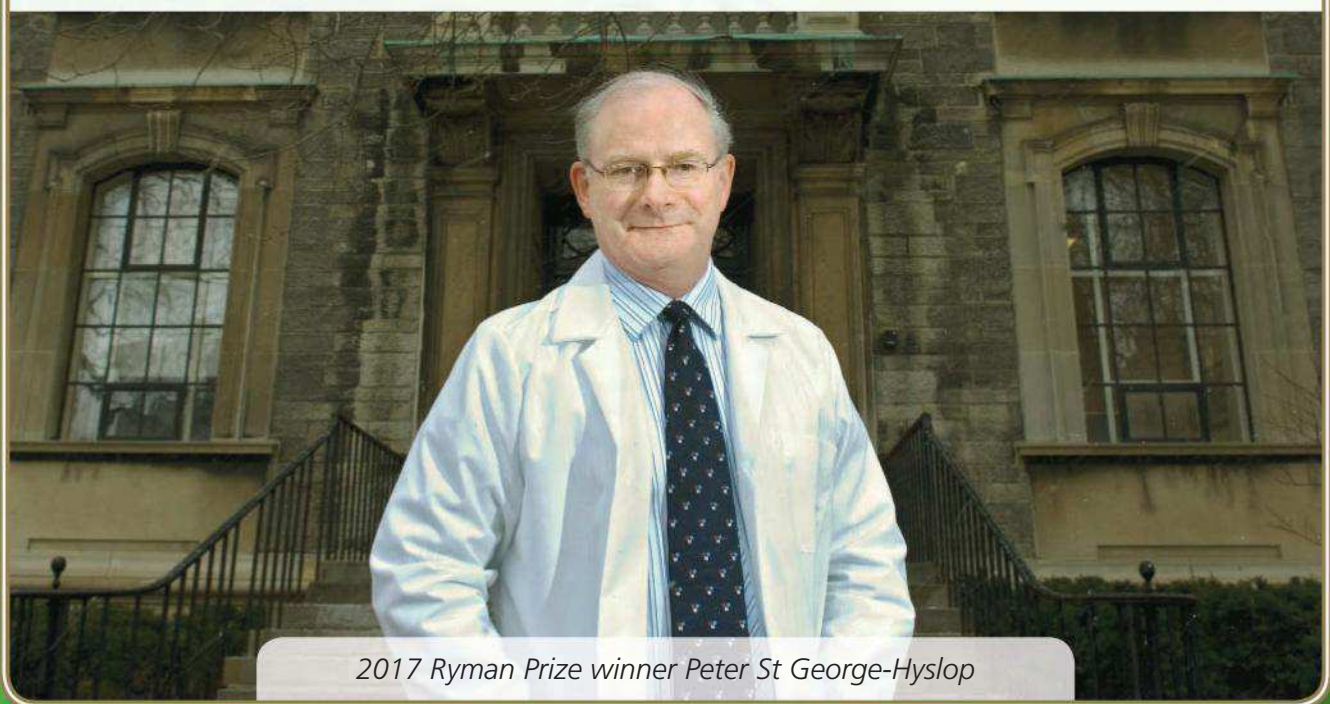

2017 Ryman Prize winner Peter St George-Hyslop

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Bodysuit let me feel VR shoot-out

Timothy Revell

OOMPH! I've just been shot in the back and the impact reverberates across my shoulders. Luckily for me and the rootin'-tootin' cowboy I've just blasted to smithereens, everything I'm experiencing is in virtual reality. But rather than simply seeing and hearing the Wild West scene around me, the suit I'm wearing lets me feel it too.

The Teslasuit is fitted with small components that produce electric shocks. These don't feel like electricity, but they cause my muscles to move. Whenever I fire my virtual pistol, a few targeted zaps force my hand to recoil as if I were holding a real one.

"It's like a wearable computer on the surface of the skin," says Dimitri Mikhalchuk, senior vice president of the company, who was showing me the suit ahead of its UK unveiling at the Future Tech Now show in London last week.

As well as providing electric shocks, the suit can warm or cool different parts of the body depending on the virtual scenario. If there is a fire in the scene, you can feel it. The Teslasuit also has nearly 100 sensors that monitor such things as the user's movements and heart rate.

The firm wants it to be used beyond just gaming. For example, astronauts on the International Space Station quickly lose muscle mass due to the lack of gravity, so must exercise for a few hours a day. "Teslasuit could help stimulate specific muscles and monitor any changes," says Mikhalchuk, who recently presented the suit to NASA.

The suit currently costs a few thousand dollars, but Mikhalchuk says this is expected to eventually fall to less than $1000.

Although the suits aren't yet available to the general public, the first batch has been sold for companies to use for VR training. This includes simulations to help people prepare to work in hazardous environments, such as on oil and gas rigs, as well as those to train security staff. The firm says the suit could also be used for hospital rehabilitation programmes or to train athletes.

The Teslasuit is battery powered and has no external wires. It can do any processing required on chips embedded inside or it can stream the data via Bluetooth to a larger computer to deal with.

One potential risk for a suit like this is someone maliciously creating a game that electrocutes or incapacitates the wearer. But the team says safeguards are in place to limit any attempts to exceed medically safe limits.

My suit didn't provide a flawless experience. Not all the zaps worked perfectly, with some buzzing me in a slightly unpleasant way, more than just tweaking my muscles as they were supposed to. But Mikhalchuk says that was because the demonstration suit was slightly too big for me. To work effectively it needs to be skintight.

Ultimately, Mikhalchuk and his colleagues want to make the next generation of clothing. "I actually wear my suit whenever I'm flying," he says. "Especially on a long-haul flight when the muscle stimulation is fantastic." ■

Timothy Revell was trigger happy, but not fast enough on the draw

TESLASUIT

Older people still make new brain cells

PEOPLE in their 70s seem to produce just as many new neurons as teenagers. The discovery could provide clues as to how we can keep our minds sharper for longer.

In mammals, most brain cells are created at or soon after birth and aren't renewed. Recently, it was found that the human hippocampus, linked with learning and memory, produces new neurons throughout life. But this ability, called neurogenesis, was thought to plummet after middle age.

Now, Maura Boldrini at Columbia University in New York and her colleagues have analysed the hippocampi from 28 people, aged between 14 and 79. These were examined soon after each person's death to check for the number of new neurons they contained, and other signs of neuron function and activity.

Similar numbers of new neurons were found throughout each hippocampus, regardless of a person's age. The team estimates that each person was making about 700 neurons a day when they died (*Cell Stem Cell*, doi.org/cm4z).

"New neuron growth has never been studied before in people who didn't have any brain disease or end-of-life stress, with tissue taken within 24 hours of death," says Boldrini. "Our results show that healthy older people can form just as many new neurons as younger people. If we know what is happening in these people to keep their neurons forming, then maybe we can use it to help others age more healthily too."

"If we can find out what is happening, we may be able to help others age more healthily too"

The number of new neurons may still be a lot higher in newborns and young children, says Jeff Davies at Swansea University, UK. He would be interested to see the study repeated in people who do and don't exercise. "This would provide some insight into whether the production of new neurons can be modified by environmental factors in humans to promote healthy brain ageing," he says. Helen Thomson ■

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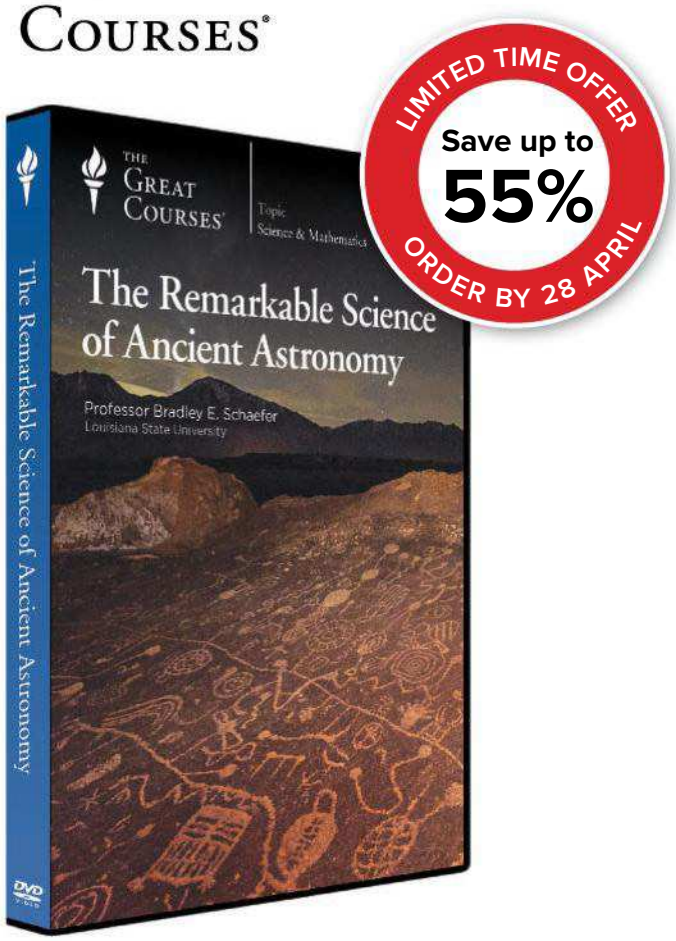

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Wasps drum to tell others of food

Richard Kemeny

WASPS literally drum up interest in food, banging their abdomens against the walls of their nest to inform their nestmates that food is available.

We have known since the 1960s that several species of wasp perform "gastral drumming" from time to time – banging their abdomens against their nest walls in a series of short bursts.

The scientists who first reported this behaviour thought it may be a signal that the wasps were hungry. Meanwhile, other researchers suggested the wasps might be telling nestmates about food sources. Such "recruitment" behaviour is common in social animals, from house sparrows to naked mole rats.

Benjamin Taylor at the City University of New York and his colleagues have now put the two ideas to the test. The team took six colonies of German yellowjacket wasps (*Vespula germanica*) and housed them in artificial nests.

The wasps were allowed to freely forage for a day, but the next day they were shut in and given only water, or a sucrose solution. On the third day, the exit was opened again.

Drumming declined when the wasps were given only water, suggesting it was not a signal of hunger. The wasps drummed more when sucrose was offered, and the levels of drumming consistently returned to a baseline level on the third day. This suggests that the wasps drum to alert each other to the presence of food (*The Science of Nature*, doi.org/cm4d).

"These creatures, despite their importance, have been much misunderstood and maligned"

It is not clear whether the drumming conveys anything about the location or amount of food. Honeybees famously perform an ingenious "waggle dance" to tell each other about food sources. The angle of the dance points the way, its length reveals the distance from the hive, and the number of runs in each dance gives an indication of the food's quality.

Might the drumming be the wasp version of the waggle dance? There are some tentative hints.

"It's amazing how bouts might only include a couple of drums in one instance, and in others it can last for several minutes," says Taylor. "The thought here is that it might contain more information about the resource."

It is an exciting possibility, says Amy Toth at Iowa State University. "If so, this behaviour would stand as one of the most complex known recruitment signals in animal societies, akin to the waggle dance of honey bees."

It is also possible that wasps might send negative feedback signals, for instance warning each other off poor food sources, says James Marshall at the University of Sheffield, UK. Such signals have been seen in honeybees and ants, and "enable really sophisticated collective behaviour".

Such signalling could change our perception of wasps. "These creatures, despite their interesting biology and ecological importance, have been much maligned and misunderstood alongside their much more popular bee cousins," says Toth. ■

From astronaut stools to Martian tools

WASTE not, want not. A method for turning faeces into plastic could come in handy for Mars pioneers.

Interplanetary travellers face two big challenges: how to transport all the tools and equipment they need from Earth, and what to do with all their waste. Mayi Arcellana-Panlilio at the University of Calgary, Canada, and her colleagues wondered if they could find a simple solution to both.

They genetically engineered *Escherichia coli* bacteria to convert human faeces to a type of plastic called polyhydroxybutyrate. Using a 3D printer, they showed this plastic could be made into small tools like wrenches (*bioRxiv*, doi.org/cm42).

"When you're planning space missions, there's no way you can predict everything you'll need," says Arcellana-Panlilio. "The nice thing about this plastic is that it can be moulded into whatever you want."

The team envisages astronaut faeces being collected by vacuum toilets into tanks, where bacteria would feed on fatty acids in the stool and produce plastic. Tanks, pumps and filters would need to be transported to Mars, but the total weight of the equipment would be less than one-fifth that of the water processing unit on the International Space Station, says Arcellana-Panlilio.

The next stage will be to see whether it is possible to extract the tiny plastic granules from the bacteria without the normal pull of gravity. In July, two students will test this during a flight on an aircraft that simulates microgravity. The team is also looking at ways to make different types of plastic of varying strengths and flexibilities.

It's not just people on Mars who could benefit – sewage could also be converted into plastic on Earth. Unlike other plastics, polyhydroxybutyrate is not made from fossil fuels and is biodegradable, so it is kinder on the environment, says Arcellana-Panlilio.

Alice Klein ■

Ancient neutrinos shaped the cosmos

Anil Ananthaswamy

NEUTRINOS that filled the universe a mere second after the big bang make up a third "dark" component of the cosmos, alongside dark matter and dark energy. For the first time, we have detected how these particles influenced the large-scale distribution of galaxies.

Moments after the big bang, our universe was a seething sea of particles, packed together and constantly bouncing off one another. Among the first to break free from this dense plasma as the universe expanded were neutrinos, which then formed the cosmic neutrino background. These neutrinos are everywhere, but are impossible to detect directly because of their low energies. Now, cosmologists have new, indirect evidence of their effects (arxiv.org/abs/1803.10741).

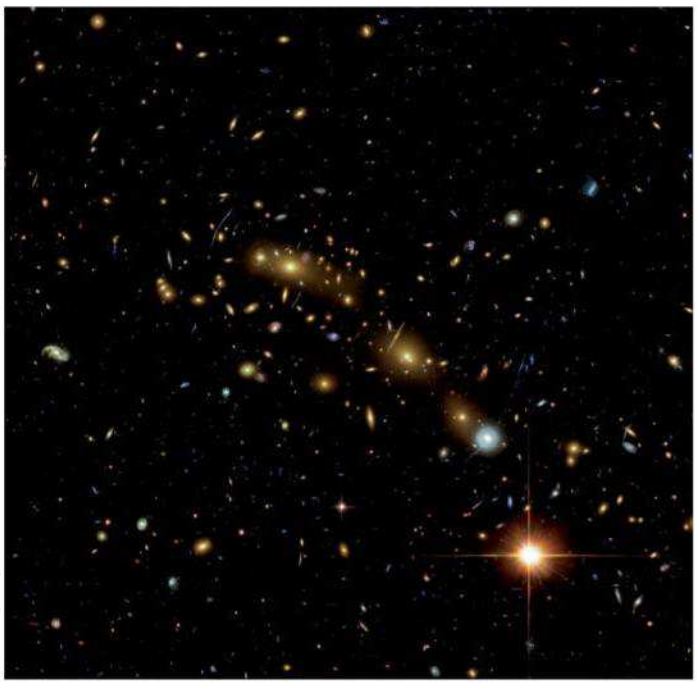
According to the standard model of cosmology, about 30,000 years after the big bang, random quantum fluctuations led to some regions having more dark matter than others. Normal matter gravitationally fell towards these pockets, only to rebound away as photons in the dense plasma pushed back against particles of matter. Thin, dense shells of normal matter began speeding away from each pocket of dark matter like sound waves from a popped balloon.

Shells of neutrinos did the same. These were larger than the shells of normal matter because neutrinos are lighter and so travel faster. The gravitational influence of the neutrino shells subtly changed the size and shape of the shells of normal matter.

Now, Daniel Baumann at the University of Amsterdam in the Netherlands and his colleagues have found evidence of these minuscule changes, by looking at the way galaxies are clustered.

When the universe cooled enough to stop both types of shells from propagating outward, about 380,000 years after the big bang, they were frozen in time. The shells became regions where more galaxies eventually formed, because they were denser than other areas of space.

To see the effect of the neutrinos, Baumann and his colleagues analysed the data from a survey of roughly 1.2 million galaxies, out to a distance of about 6 billion light years, carried out by the Sloan Digital Sky Survey-III.



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Galaxy clustering now is distorted by neutrinos from the big bang

Theory predicts that in such a large volume of space, one should find more pairs of galaxies that are about 500 million light years apart than any other distance, representing overlapping shells in today's expanded universe. Earlier studies had indeed found more such galaxy pairs.

Baumann's team showed that the influence of neutrinos in the early universe can be detected today in how galaxies are distributed. The shells of normal matter that were subtly stretched and distorted by neutrinos have since evolved with the expanding universe. The shape and size of these shells, determined by an excess of galaxies in these regions today, are consistent with our ideas of that warp.

"It's yet another successful test of the standard model of cosmology," says David Spergel at Princeton University. ■

Why we have better eyesight at twilight

OUR sight is sharpest at dawn and dusk – and now we may know why. It is not a result of changes within our eyes, but of how the brain processes visual signals.

The brain has continual background activity. But this lessens in the visual centres around sunrise and sunset, which may improve our perception of visual information in the low light levels at these times.

"You are sensitising your brain," says Christian Kell of Goethe University in Germany. "A weak signal coming in will have a higher signal-to-noise ratio."

Our eyes adapt to dim light in several ways, such as by the pupils dilating to let in more light rays. But irrespective of light levels, our eyesight gets better around the times of dawn and dusk. This has even been seen in people who lived for long periods in underground bunkers, cut off from natural light.

To find out why, Kell's team asked 14 men to spot when dim crosshairs flashed up on a screen at six different times of day. They also had their brains scanned, both as they did the task and while they rested.

There were two noticeable peaks in their performance on the visual test: at 8.00 am and 8.00 pm, roughly corresponding to the time of sunrise and sunset (*Nature Communications*, DOI: 10.1038/s41467-018-03660-8).

"Around the times of sunrise and sunset, we see a sensitisation of all the sensory areas of the brain"

At these times, there was also a fall in background activity in three brain areas that process information from the eyes, ears and sense of touch. "We see a sensitisation of all the sensory areas of the brain," says Kell. He thinks that is because people are more reliant on their vision and other senses in dim light.

"Pre-industrial tribes are very active during dawn and dusk, which means they are also in danger from animals then," says Kell. This could explain why we evolved to have sharper senses at these times.

Clare Wilson ■

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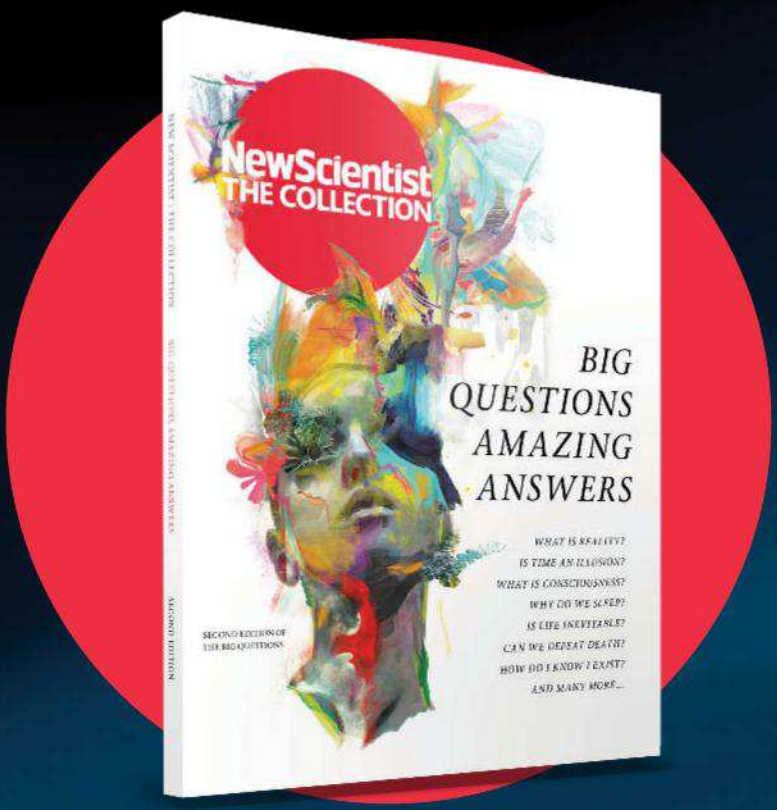

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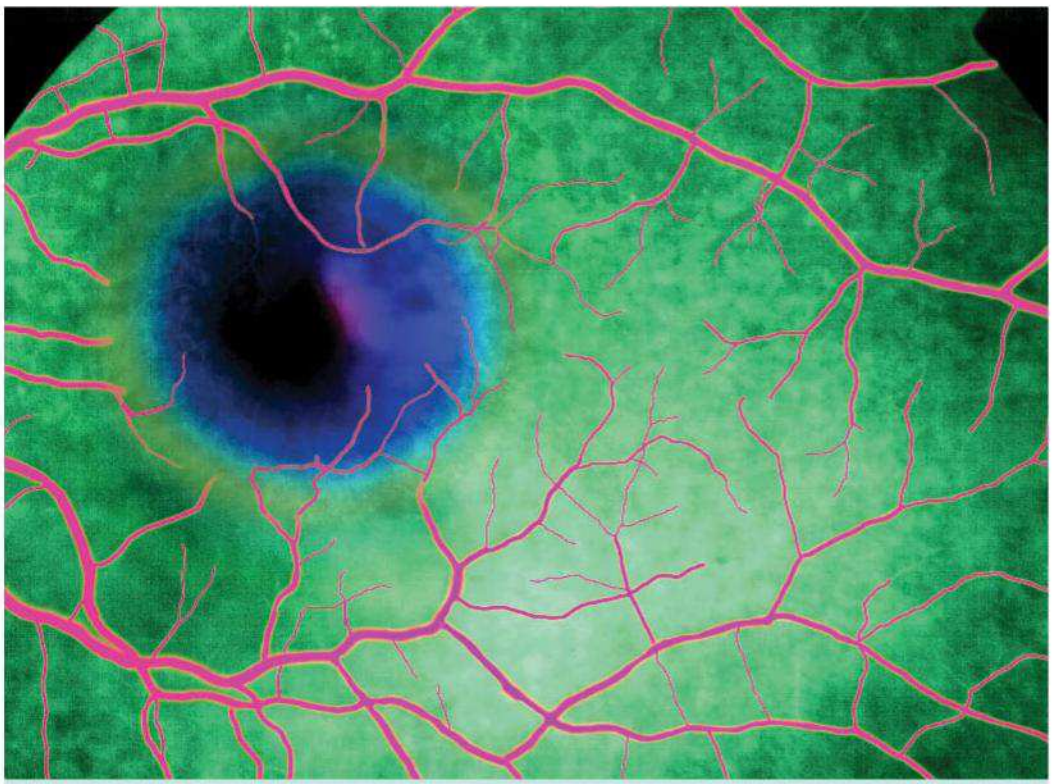

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Eye implant reverses form of age-related blindness

A PATCH implanted at the back of the eye has improved or stabilised sight in four people with a condition called age-related macular degeneration. The treatment let one 69-year-old woman read 24 letters on a standard eye chart when she could previously manage only seven.

The patch consists of eye cells made from human embryonic stem cells. It has been designed for treating the "dry" form of macular degeneration, caused by deposits on the retina gradually killing retinal pigment epithelial cells, which support light-capturing cells. This form accounts for 90 per cent of all cases and affects 1.7 million people in the US.

Similar patches have already had some positive results for the "wet" form, in which blood vessels invade and destroy the retinal pigment epithelial cells.

To test their idea for the dry form, Amir Kashani of the University of Southern California in Los Angeles and his colleagues coated 6 by 4-millimetre slithers of polymer with retinal pigment epithelial cells they had grown, then transplanted these into four people. Each had one eye treated, and one eye left untreated as a control.

Over a year, the patch appeared to stabilise the disease in all four treated eyes, while the untreated eyes continued to deteriorate (*Science Translational Medicine*, doi.org/cm38). The team is now planning a larger trial in people who have earlier stages of the disease.

Horde of black holes at galaxy's heart

AS MANY as 10,000 black holes may be buzzing around in the centre of the Milky Way galaxy.

The galactic centre is known to host a humongous black hole called Sagittarius A*, whose mass is equivalent to 4 million suns. Simulations have long suggested that many smaller black holes, with masses close to the sun's, also exist in the centres of galaxies including the Milky Way, but only one has ever been found.

Combing through archival data from NASA's Chandra X-ray Observatory, Charles Hailey at Columbia University in New York and his colleagues were able to tease out signals that appear to come from 12 stellar-mass black holes, each with a star orbiting it (*Nature*, doi.org/cm3z).

Each black hole continuously steals material from its companion's surface. That pilfered plasma swirls about the black hole's maw, heating up and releasing X-rays we can spot.

Extrapolating from the data on the 12 bright black holes, the team deduced that 300 to 500 fainter black hole binaries were spinning around in the galactic centre. As only 5 per cent of black holes are thought to have stellar companions, the team believes 10,000 black holes of this size could exist in the central bulge.

Waggling robot natters with bees

ROBOTS are talking with bees. A robotic bee can tell real bees the best places to forage, and at least some of the time they seem to get the message.

Bees communicate via the so-called waggle dance, where the dancer wiggles its body while moving in a figure of eight. The orientation and the length of the movements tell other bees the direction and distance of a food source. RoboBee can mimic this dance (arxiv.org/abs/1803.07126).

RoboBee is made of a cylindrical piece of sponge with plastic wings and is attached to the end of a rod that controls its movements. Though it doesn't look much like a bee, it is so dark inside the hive that visuals aren't everything.

On some days, the robot worked perfectly and on others the bees ignored it, says Tim Landgraf, who developed RoboBee with colleagues at the Free University of Berlin in Germany.

Palm trees seen changing sex

FOUR palm trees have been spotted changing from male to female for the first time.

While many plants have male and female sex organs, palm trees were thought to be either male or female, or "dioecious". It seems this is not the case, says Rodrigo Bernal at Quindío Botanical Garden in Colombia.

He and his colleagues surveyed more than 160 wild-growing Quindío wax palms (*Ceroxylon quindiuense*) in Colombia. Four males were switching to female (*Ecology*, doi.org/gc7qvb).

Sex changes have been seen in a few other dioecious plants, like maple trees. No one knows why it occurs. One idea is that the switch to producing seeds helps the palms colonise new areas faster.

Fighting trolls with your friends

YOU can tackle trolls with a little help from your friends. A tool called Squadbox lets people use their friendship group to filter abusive messages.

If someone is being targeted with online abuse, then friends, support groups or other trusted parties can access their email account with Squadbox to act as personal moderators. Known contacts can also be whitelisted, so their emails go straight through without moderation, or a specific email address can be blacklisted if it is a particular source of abuse.

The tool works best for bursts of harassment rather than a sustained, constant campaign, says Amy Zhang at the Massachusetts Institute of Technology, one of Squadbox's creators. This is because amateur moderators could be overwhelmed by the vitriol in the messages, or the sheer volume could lead to prolonged delays in receiving the non-abusive emails.

Squadbox comes with privacy trade-offs because your friends have to read some of your messages, says Liam McLoughlin at the University of Salford, UK. But it has a "place in combating abuse", he says.

The team will present the work at the conference on Human Factors in Computing Systems in Montreal, Canada, later this month.

STANISLAW PYTEL/GETTY

First lab-grown brains with blood vessels

GIVING miniature human brains their own blood vessels could enable researchers to grow bigger "organoids" to help us better understand how the brain works.

Organoids are small, 3D clumps of tissue that behave more naturally in the lab than traditional, flat cell cultures. Researchers use human brain organoids to explore how parts of our brains develop. However, they seldom reach more than 2 millimetres in width because they have to be kept alive in a liquid containing growth factors and nutrients.

If the organoids get too big, the centre dies, because not enough nutrients can penetrate by diffusion, says Ben Waldau at the University of California at Davis.

To overcome this, Waldau and his colleagues have created mini-brains that are threaded with blood vessels. Both the brain and the blood vessel tissue were grown from cells donated by a person undergoing a routine operation. The cells were taken from the dura membrane, which surrounds the brain. By exposing the cells to different chemical cocktails, the team encouraged some of them to become brain organoids and others to become blood vessel cells.

After a month, Waldau coated the brain organoids with a gel containing blood vessel cells. A month later, blood vessels had grown into the centre of the organoids (*NeuroReport*, doi.org/cm37).

The next step is to see if this will enable brain organoids to grow bigger.

Old SIM cards are good as gold

THERE'S gold in them thar SIM cards, but most of it gets thrown away – $22.2 billion was wasted in 2016 alone. Currently, only 20 per cent of e-waste is recycled, but that could get a boost thanks to a cheap new way of chipping the gold off SIM card surfaces.

Dale Huber of Sandia National Laboratories in New Mexico and his team developed a process that creates microscopic bubbles on the surface of a SIM card. These bubbles explode violently, producing high pressures and temperatures up to 4700°C (*Small*, doi.org/gc7rbt).

Huber and his team first covered the surface with a surfactant, the molecules of which form a single thin layer. Then they covered it with a layer of another surfactant and water. When they exposed it to ultrasonic waves, microscopic bubbles formed and collapsed in tiny but powerful explosions that cratered the SIM card's surface. Microjets of gold particles were ejected from the craters and captured in the liquid above.

Huber says the process is cheap and environmentally friendly, unlike existing methods that use incineration or harmful solvents to extract precious metals.

MARTHA HOLMES/NATUREPL

Some whales have got talent

BOWHEAD whales may be the most versatile singers in the mammalian world. Recordings show that they regularly devise entirely new songs, rather than modifying existing ones.

Kate Stafford at the University of Washington in Seattle and her colleagues put hydrophones in the Fram Strait between Greenland and Svalbard, Norway. Over three years, these recorded 184 bowhead whale songs (*Biology Letters*, doi.org/cm39).

Some of the songs sound like power tools. Others resemble long, sweeping belches and snorts, with gentle whistling in the background.

The tones in bowhead songs are not restricted to single notes like human singing. "Bowhead whales have the capability to produce two different sounds at once, and we don't know how they do that," says Stafford. "The alphabet of notes seems almost unlimited."

Bowhead whale songs may be the most complex produced by any mammal except humans. They also change more over time. "Each year, there are dozens of distinct songs that are not graduations from one song to another, but are completely different," says Stafford.

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The arms race in space

The US is making noises about beefing up its military presence off planet. Where will it lead, asks **Leah Crane**

WAR in space is a hot topic in the US government. Last year, Congress considered and rejected a proposal to create a standalone "space force" to deal with threats in orbit, and in March, President Donald Trump brought it up again.

"Space is a war-fighting domain, just like the land, air and sea," Trump said at Marine Corps Air Station Miramar in San Diego. "We should have a new force called the space force. It's like the army and the navy, but for space, because we're spending a lot of money on space."

"We should have a new force called the space force. It's like the army and the navy, but for space"

The Trump administration's position was further detailed last month with the announcement of its national space strategy. It states that US "competitors and adversaries have turned space into a warfighting domain" and promises that any attacks on US space assets will be met with a deliberate response.

They sound like fighting words. But any space war won't be like *Star Wars* – no humans will zoom around in slick spaceships, death will not rain from the skies and it is unlikely that anything will be blown up.

"It's not fighter jocks, it's not marines, it's not special-operations guys," says Todd Harrison at the Center for Strategic and International Studies in Washington DC. "It's a bunch of engineers sitting in a control centre and sitting in labs. The space domain is going to be dominated by nerds."

We know this, because the US space force already exists. The Air Force Space Command has been around since 1982 and employs more than double the number of people at NASA, the US civilian space agency, to operate and protect military satellites. The space force proposal for Congress wasn't really about creating a new branch of the military, but part of a long-running push to move the space command out from under air force leadership, making space a higher priority.

Plus, sending a human to fight a war in space is simply not efficient. "Humans are fragile and sustaining them in space takes a lot of support," says Laura Grego at the Union of Concerned Scientists in Cambridge, Massachusetts. "The Chinese and the Russians aren't going to send marines to space either, because they know physics too."

Physics also rules out orbital bombardment. Objects in orbit move at high speeds, so aren't over a single spot on the planet for long. That means attacking a specific area at short notice would require placing hundreds of weapons in orbit to ensure one is overhead at the right moment. An aircraft carrier loaded with bombers or ballistic missiles would be much more effective.

Deadly debris

What war in space really comes down to is satellites – using them, destroying them and defending them. The US and Soviet Union started launching satellites in the 1950s and many were designed to spy on the military operations of other nations or to target nuclear weapons. This dissuaded any attacks on satellites, because one nation would instantly know that the other was responsible and probably attempting to disable its nuclear capability. Space war would swiftly become nuclear war, so satellites were a key part of nuclear deterrence.

Since the cold war ended, satellites have increasingly been used in everyday military operations. They enable weapons targeting, espionage, GPS tracking and secure communications, making them juicy targets. This proliferation has weakened the deterrence aspect of satellites – no one would launch a global nuclear war on the back of one destroyed piece of hardware. That makes space war more feasible. "We have these valuable space assets, and they're fairly vulnerable because it's hard to protect things in space" says Grego.

Disabling an enemy satellite has also become easier. Previously, the only options were shooting a projectile at it or smashing your own satellite into it. Such "kinetic attacks" tend to be seen as a bad idea. In 2007, China launched a missile to destroy one of its own weather satellites. This test created more space debris than any other event in history – thousands of shards more than a

In a space war, no gun-toting humans would be involved

IMAGE VAULT/ALAMY STOCK PHOTO

U.S. AIR FORCE PHOTO/TECH. SGT. BENNIE J. DAVIS III/ALAMY

The US Space Command is currently under the wings of the air force

few centimetres across, and many more smaller ones.

"That debris stays in orbit, zooming around at high speeds," says Grego. The resulting high-velocity shards endanger everyone's assets, including those of the attacker and innocent bystanders.

That is why a space war is most likely to be waged more discreetly, with jamming, spoofing and hacking. Jamming a satellite is fairly simple: you just need a device that emits a lot of noise in the radio or microwave wavelengths used by the target satellite, so that genuine signals can't be received. Spoofing is similar, but the attacker also creates a false transmission that masquerades as the target satellite's signal.

Examples of satellite jamming and spoofing have been reported all around the world, from governments blocking television or radio signals, to ships being sent fake location data, to private citizens jamming GPS signals so they can't be tracked.

Actually hacking into a satellite and taking control of it is more difficult. There have been only a few reports of hackers taking over satellites, including one against a US National Oceanographic and Atmospheric Administration satellite in 2014. Hackers in China reportedly temporarily took over the satellite's command and control system but didn't send it any directives.

"The Outer Space Treaty prohibits deploying weapons of mass destruction in space"

This is cyberwarfare on a new stage, and international law has yet to catch up. "In terms of legal restrictions on war in space, there is precious little," says Frans von der Dunk at the Nebraska College of Law. The Outer Space Treaty prohibits deploying weapons of mass destruction in space, but it doesn't have any specific rules about regular weaponry. More importantly, because it was drafted in 1967, it doesn't say anything about cyberwarfare.

In theory, countries could sign a new treaty agreeing to outlaw these technologies in space – the UN Disarmament Commission included discussions on preventing an arms race in space in its 2018 agenda – but in practice that may prove difficult. "The number-one conundrum of dealing with space policy issues is the dual-use nature of most space technology," says Joan Johnson-Freese at the Naval War College in Newport, Rhode Island. Any satellite with thrusters intended for legitimate uses could also be manoeuvred to sidle up next to another satellite and crash into it. A laser normally used to track satellites could also dazzle one and prevent it receiving signals from its operators.

All or nothing

Of course, for a treaty to work, you have to get everyone to sign up. "The landscape of states with interests in space has expanded enormously, which makes it much harder to agree on a single set of rules," says von der Dunk. "You need basically everyone to agree, because if you have just one outsider, that country is free to do what it wants and the whole system collapses."

A robust space treaty would need to be enforced through diplomatic sanctions against any nation that breaches it, but identifying aggressors will be difficult. In space, everything happens so far away that it is hard to tell where an attack came from.

If a space war kicks off, this added confusion could be a major problem. "If one satellite goes out and there's debris everywhere and it hits another satellite, was that debris or was it another country continuing escalation?" says Johnson-Freese. "Once it starts, it's hard to stop."

This uncertainty means even an accident mistaken as an attack could lead to extreme responses. With the US engaged in face offs with Russia, China and North Korea, tensions on the ground are high – meaning an escalation to orbit is looking increasingly possible. "Are we going to have a space war? Yes. It will probably be part of any major war we have in the future," says Harrison. ■

Keep marching

The global rally against the denigration of science was a huge event in 2017. There are many reasons for a repeat, says **Jonathan Berman**

WHEN I first started recruiting for a scientists' march on Washington DC in early 2017, it seemed like an uphill battle. I was just a researcher without money, connections or crowd-pulling charisma, moved to action by the election of Donald Trump, a powerful climate change denier and anti-vaxxer, as US president.

Of course, science was already beset with human problems. Research funding had been declining and although people often said they loved science, they would then say how acupuncture had "cured" their back pain, or produce a salad of words like "quantum" and "consciousness" with no regard to physics or neuroscience. Science was well loved, but much abused and rarely understood. I felt nearly alone, facing a world of fantasists, believers and deniers.

That feeling turned out to be wrong. Thanks to thousands of volunteers and hundreds of thousands of protesters, the Washington event became the March for Science, the largest public science education event in history. It extended to cities around the world and saw more than 1 million people participate.

It is hard to quantify its impact. But a year later, more scientists than ever have run for political office. There are new expos and outreach projects. Sound science seems to be entering the cultural lexicon as a virtue, like honesty or hard work. More people are aware of science denial and more are taking on leadership roles in science education and advocacy. And science advocates are poised to rally again. The second March for Science is on 14 April. There are good reasons for a repeat.

Abuse and misunderstanding of science persists. Anti-vaccine

Battle lines

A row over a university's military AI project is a sign of the times, says **Paul Marks**

ARTIFICIAL intelligence plus death always stirs up controversy. Last month, it was about a self-driving Uber car that ran over and killed a woman crossing a road in Arizona. And then a Tesla, driven by its software, hit a central reservation in the US, killing the driver.

While there is fierce debate over the real-world capabilities of driverless cars, there is one area where there is broad support for keeping AI at bay: weapons that can target and fire without human oversight.

Cue more headlines about AI and death last week with the announcement of a threatened boycott of KAIST, a South Korean university, over fears it would work on such weapons. More than 50 AI and robotics experts said they would stop collaborating with it if this were the case.

The spark for this was KAIST establishing a research centre on AI and national defence, with arms firm Hanwha Systems as sponsor. The boycott signatories demanded that the institution does not "develop autonomous weapons lacking meaningful human control". In response, KAIST affirmed that it wouldn't create such weapons and that its research in this area was committed to including meaningful human control.

"Experts are concerned about weapons that can target and fire without any human oversight"

The exchange came amid ongoing UN moves to quash autonomous target-destroying weapons, with 23 nations already backing a ban. There is also a wider debate on military AI.

This isn't about AI having no place in armed forces. That view was made clear in evidence to an upcoming report on AI from the UK House of Lords, including its role in weaponry. Noel Sharkey, a UK roboticist who is a signatory to the KAIST protest, said that

attitudes were partly to blame for a quadrupling of measles cases in Europe in 2017. Last year, the US president abandoned the Paris Agreement on climate change. Staff at the US Centers for Disease Control and Prevention were advised not to use terms such as "science-based". Government sites have had their climate change data erased. Science adviser positions have been left vacant or eliminated.

Science itself has no end point – it will never know all there is to be known. Likewise, building a society that appropriately understands, values and uses science is unlikely to have a fixed end. If the problems we hope to address still exist, we must carry on attempting to find new ways of solving them.

Since I first started work on the 2017 march, I have come to realise I am not alone in desiring a society that appreciates science. Every science activist, no matter how lacking in funds or connections, can experiment to fulfil that desire. Some of those experiments will work. ■

Jonathan Berman is a postdoctoral fellow at the University of Texas Health Science Center in San Antonio and was a lead organiser of the March for Science 2017

his opposition is to weapons that use autonomy for "target selection and the application of violent force".

His thoughts were echoed by other expert witnesses: AI should be free, for example, to find improvised explosive devices, disable bombs and predict battlefield risk. To prevent such uses would be to deny potentially life-saving advances.

But with military interest in the applications of AI growing, expect lots more reports, debate and, probably, more protests. ■

Paul Marks is a technology, aviation and space-flight writer based in London

INSIGHT ENERGY

MARIA FECK/LAIF/EYEVINE

We should look to China for renewable success

Michael Le Page

THE world added more solar capacity in 2017 than all new coal, gas and nuclear electricity-generating plants combined. That is the conclusion of a report on how much banks, private investors and utility companies invested in renewables last year.

Sounds promising. But on closer examination there are some worrying numbers in the report. They reveal that in most of the world, investment over the past few years has either changed little or fallen, often because of cutbacks in subsidies – showing that despite getting ever cheaper, wind and solar power remain heavily dependent on government support.

In fact, government investment in the developed countries whose emissions caused most of the global warming so far has halved since 2011, to $103 billion. The most shocking change is in Europe, which has set itself the goal of leading the world in tackling climate change. There, investment peaked at $126bn in 2011 and has now fallen to $41bn.

The global figures would look quite grim were it not for the astounding efforts of China, where investment in renewables has soared over the last decade to hit a record $127bn last year. This means that in China alone, investors are pouring more money into solar and wind power than in all the developed countries combined.

It is important to point out that because the cost of building wind farms and solar plants has fallen, every buck spent today creates far more electricity-generating bang than a decade ago. But if investment in developed countries had remained at 2011 levels, the world would be getting a lot more of its electricity from renewable sources than it is now.

"In China, more money is put into solar and wind power than in all the developed countries combined"

And that matters. Despite the $3 trillion spent globally since 2004, just 12 per cent of the world's electricity came from renewable sources in 2017, compared with 5 per cent in 2005, excluding large hydroelectric schemes and nuclear plants. This is projected to rise to 34 per cent by 2040, says the lead author of the report, Angus McCrone of Bloomberg New Energy Finance.

So why is investment in renewables plummeting in places such as Europe and Japan? Many factors are involved, say McCrone and his colleagues, but cuts in subsidies have played a big part. Take the UK, which has seen the biggest falls in investment, down 65 per cent last year, after slashing green policies back in 2015.

Another issue is profitability. If there is a surplus of electricity whenever the sun shines or the wind blows, the price it can be sold for falls. So the idea that market forces alone will ensure solar and wind keep growing until they replace all coal and gas plants is wrong.

But it's not all bad news. Developing countries now outspend developed ones – largely thanks to China. Even in the US, renewables investment fell just 6 per cent to $41bn, despite Donald Trump withholding funding promised as part of the Paris agreement. What's more, R&D in renewable energy rose to a record $10bn, thanks to firms boosting their spending by 12 per cent to match that of governments.

Overall, there are some reasons to be cheerful: the figures show the world is moving away from fossil fuels. The bad news is that this isn't happening as fast as it needs to if we want to limit warming to not too much more than 2°C. Governments need to step up and boost investment if there is to be any chance of success. ■

octopus
A brighter way

See how they grow

The hidden powerhouses that drive the UK economy need more support, says Chris Hulatt of Octopus Group

THERE'S something charmingly counter-intuitive about Secret Escapes. The company offers its subscribers exclusive, private deals, but grew its membership and ability to offer unique bargains through a series of prominent TV ads. In an inspired twist on traditional exclusivity, anyone can join – and for free.

However odd the idea seems, it clearly worked. Since Secret Escapes launched in 2010, industry insiders have recognised its growth as something of a phenomenon. In October last year, investors put £83 million into the company, more than doubling the funding it had received up to that point. From humble beginnings, it now operates in 21 countries, providing luxury breaks to 42 million members worldwide.

This story is an example of an emerging phenomenon: the "high growth small business". A high growth small business is defined as enjoying average annual growth

"High growth small businesses enjoy average annual growth of 20 per cent"

of more than 20 per cent while having an annual turnover of between £1 million and £20 million. The firms in this sector are Britain's secret economic powerhouse. For all its contributions, however, this sector is relatively unknown and undersupported. This is something that the Octopus Group is working to change.

"These smaller companies don't get as much airtime as they should do," says Chris Hulatt, one of the founders of Octopus. In partnership with business research consultancy Cebr, the firm has just issued its third report into the state of high growth small businesses in the UK. The document offers a number of recommendations for policy changes that would help this thriving sector achieve even more success.

When asked to identify businesses that help the UK prosper, most of us tend to think of blue chip companies listed on the London Stock Exchange. While no one doubts the importance of such firms, there are good reasons to show special interest in high growth small businesses.

One reason is that, despite making up less than 1 per cent of UK companies, they accounted for around 22 per cent of the 2016 increase in the UK's "gross value added", a measure of contribution to the economy. What's more, their ability to create jobs is remarkable. In 2016, high growth small businesses accounted for 20 per cent of all new jobs created. "I was shocked when we started learning what percentage of jobs is created by these businesses," Hulatt says. "These are a tiny proportion in terms of the number of businesses, but in terms of job creation it's a really big chunk."

And those jobs are everywhere. Gear4Music, for example is a high growth retailer of musical instruments and equipment based in York. Then there's the Manchester-based fashion retailer Missguided, which now has 650 employees. Three out of five high growth small businesses are located outside the south-east, and 70 per cent of their turnover comes from outside the capital. That is important in an era when regional economies need a boost. And wherever these businesses appear, they seed more than jobs: demand for services and infrastructure grows, for instance, creating new opportunities for innovation. Other firms offering supporting services are drawn into the region or created from scratch.

Another reason these businesses deserve support is that they are spread across all sectors. Their biggest contribution comes from the construction industry, but firms offering scientific, retail, education and manufacturing services are all part of this thriving scene. That indicates high growth small businesses are not just a passing fad, but a robust, sustainable pillar of the UK economy. Hulatt believes the success of these companies will be even more crucial as we prepare to leave the European Union.

Successful investment

The important thing to note is that none of this success happens without investment. Take the snack company Graze, for example. Graze mails personalised, letterbox-sized packs of nuts, seeds, crackers and dried fruit to its subscribers. Its boxes are also now available at UK retailers like Sainsbury's, Boots and WH Smith.

A group of eight friends started the business in 2008, and made the initial runs to the postbox themselves. Octopus Ventures, now one of Europe's largest venture capital teams, provided Series A funding in 2009,

and Graze now has 500 employees and is expanding into the US.

It is a similar story with the property firm Zoopla, which has also seen investment from Octopus. Founded in 2007, this company's website and apps now bring in more than 50 million visits each month. After years of significant investment, its revenue increased to £244.5 million in 2017 – that's a 24 per cent growth.

To repeat such successes, Octopus is recommending that policymakers further encourage investors to support high growth small businesses. "This is a sector where if you champion these businesses and focus on making policies that work for them, you can make a real difference," Hulatt says.

There has been some headway. Hulatt is encouraged by recent policy innovations such as facilitating "patient capital", where governments make it easier for investors to give the companies more time to provide a return. Another step-change came when ISA fund managers were allowed to put funds into the Alternative Investment Market (AIM), where a lot of these high growth small businesses are listed. "That's something we campaigned for, and this shows the government has listened, and that they understand the need for these support mechanisms," Hulatt says.

Octopus and the companies it backs stand to gain from such changes, of course,

> "These companies are a robust sustainable pillar of the UK economy"

and a further step forward would be if pension funds were encouraged to invest in high growth small businesses.

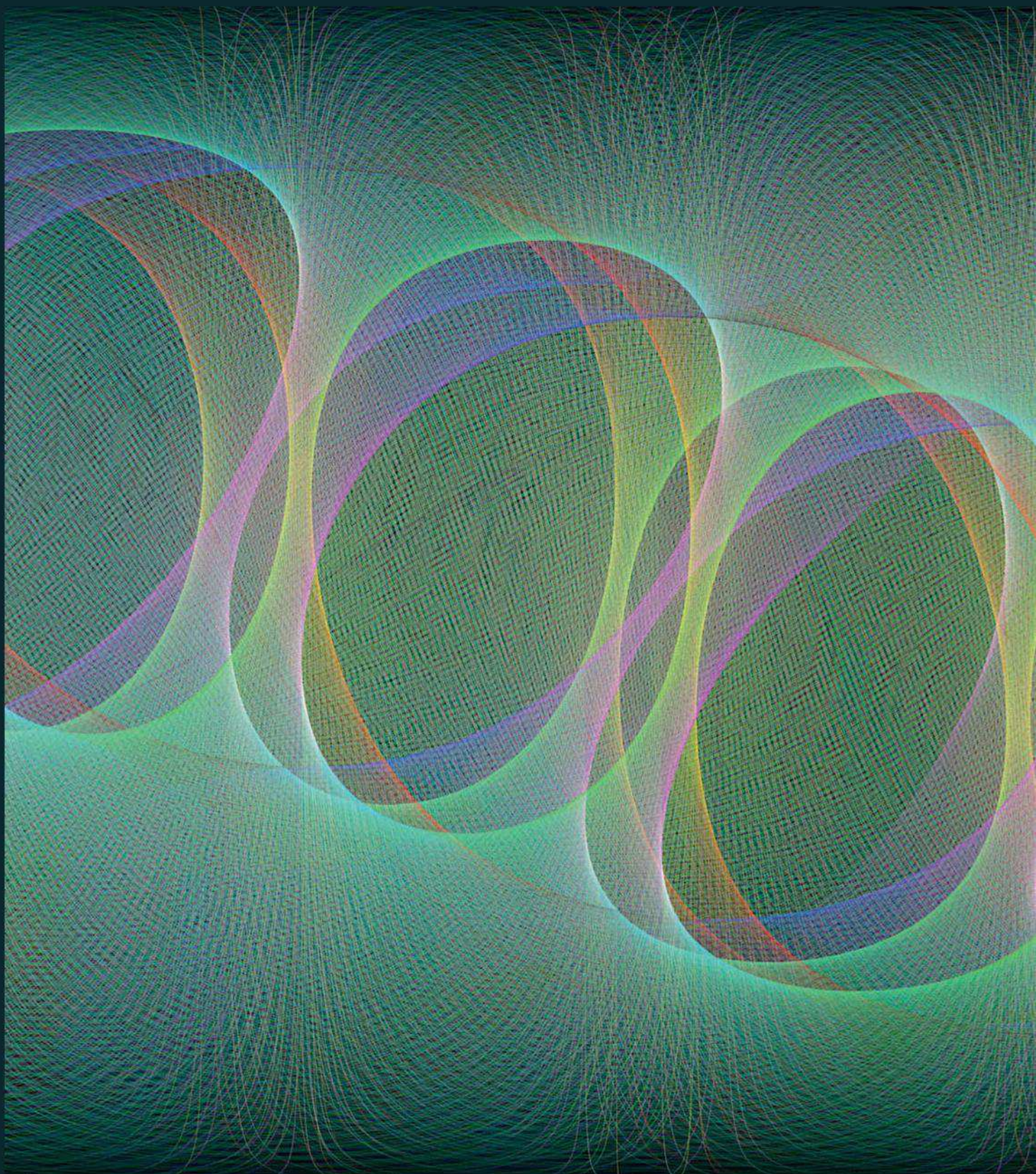
Institutional investors see them as too small, and thus too risky, for pension funds. But that is not the case, Hulatt believes. "A small allocation to UK growth capital is not going to destroy the risk profile of pension funds, and could unlock billions in extra cash, making a real difference to high growth small businesses across the UK," he says.

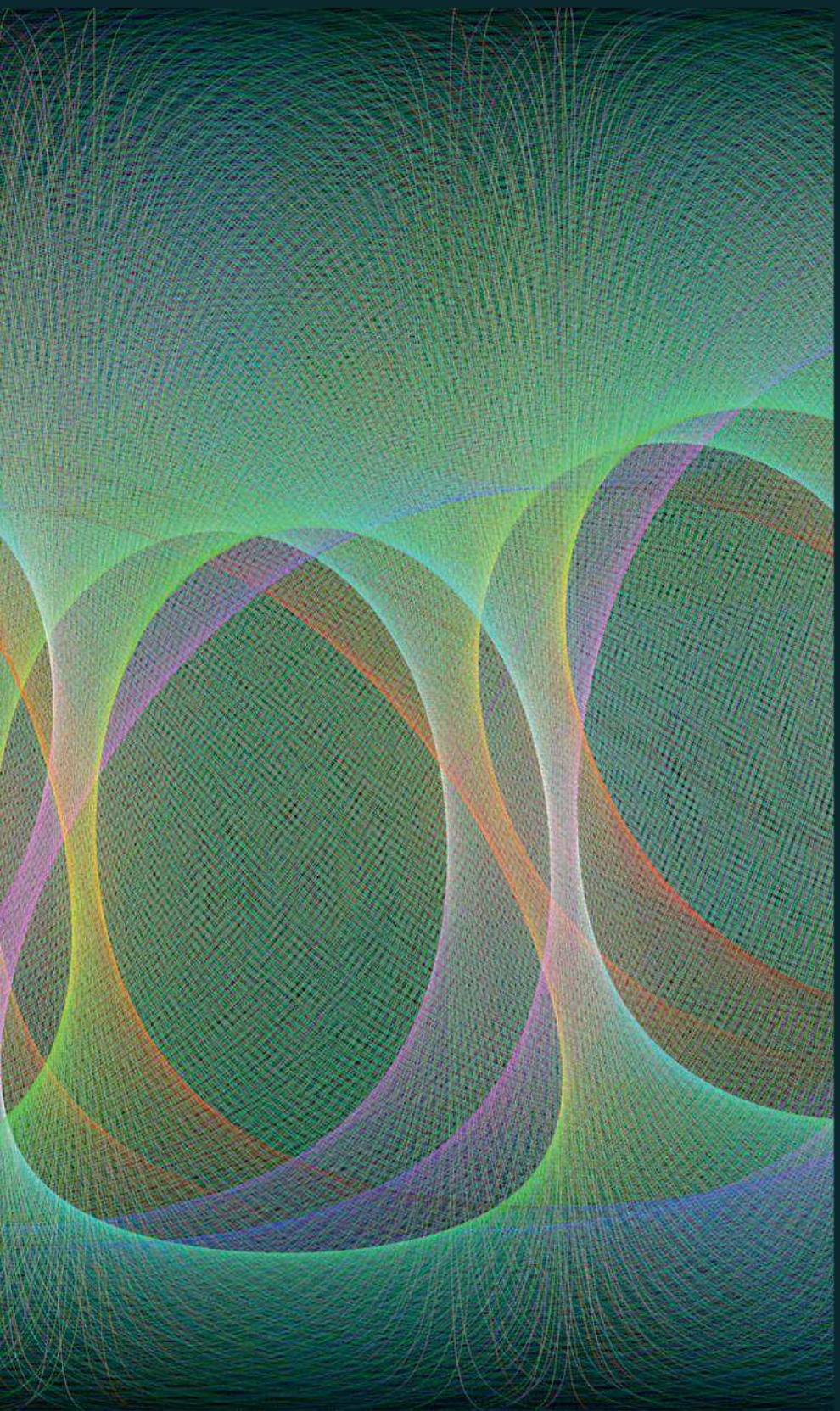
Then the world becomes your market. "Why sell up just because you've conquered the UK?" Hulatt says. "More than half of the businesses that we back have gone into the US market. If you can make a business work in a market of 60 million people and you can crack the US which is five times bigger, you can turbo-charge your growth."

Secret Escapes provides a great case study, Hulatt thinks. Octopus has invested several times, and used its experience of the US market to help shape Secret Escapes' offering there. Now this high growth small business is punching way above its weight across the world. "It's gone into multiple countries, and is growing phenomenally quickly," Hulatt says. "The support ecosystem allowed them to be ambitious – and to fulfil their ambition. But there is still more to do to make that possible for others."

Find out more at: www.octopusgroup.com

APERTURE





Swirl and whirl

PICK a line and follow it with your eyes. You are looking at this page in the same pattern as the European Space Agency's Gaia satellite looks at the sky. The neon colours in this image represent which direction Gaia was rotating as it scanned that part of the cosmos.

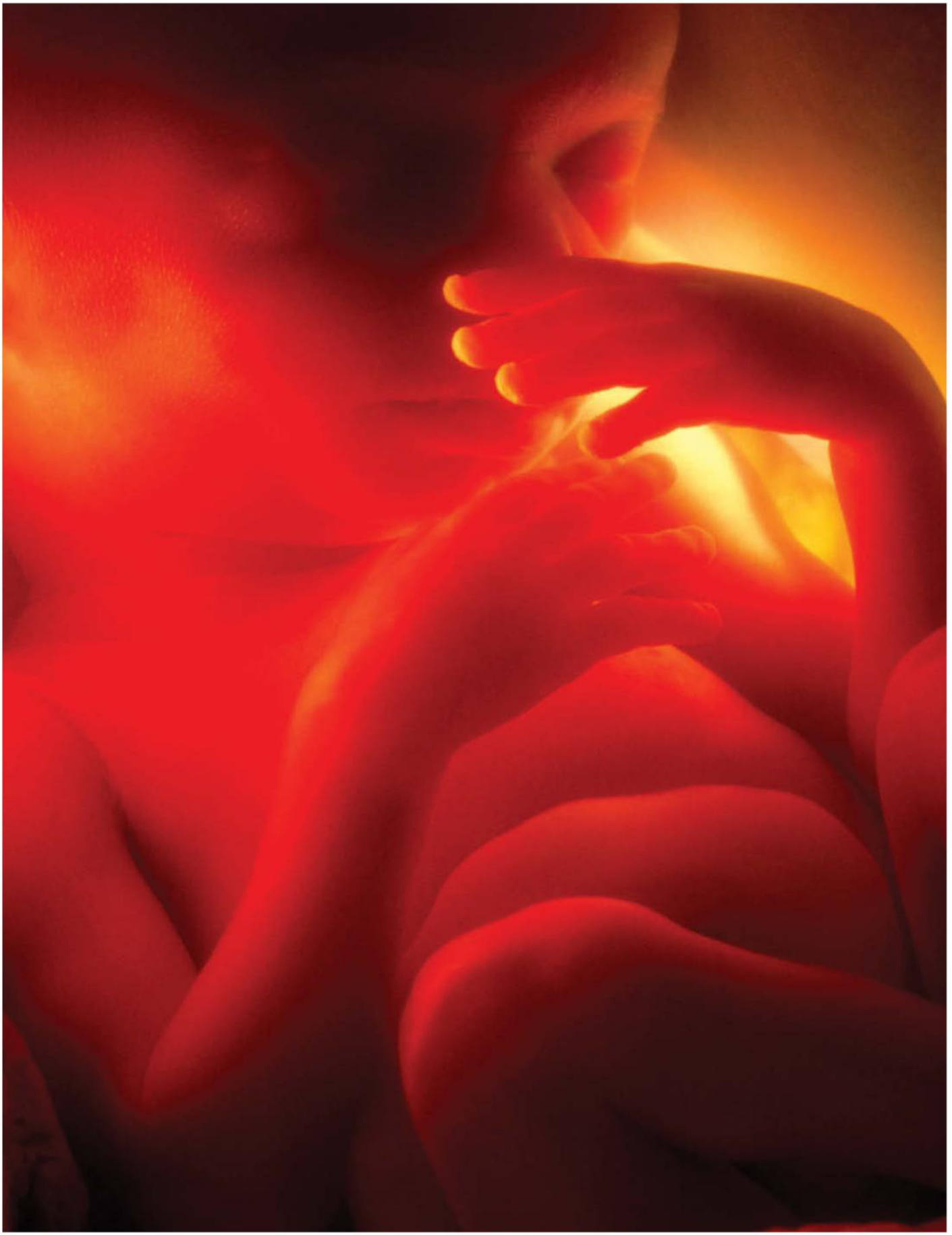
Launched in 2013, Gaia is dedicated to making the best 3D map of our galaxy we have ever had by tracking the precise distances and locations of more than a thousand million stars.

In order to do so, it rotates slowly as it glides around its orbit, allowing its two telescopes to take in the entire sky. Places where the lines intersect indicate regions of the sky that Gaia has observed multiple times. By the mission's end in 2019, this entire picture will be saturated with bright lines.

Gaia's first data catalogue, with measurements of more than a billion stars, was released in 2016. Its second release, scheduled for 25 April, will contain information on the movements and distances of 1.3 billion stars, along with less-detailed data on 360 million more.

Astronomers hope to use this data to learn more about how our galaxy formed and evolved, and what exactly it is made of. It may even help us resolve hotly debated issues like how fast the universe is expanding. Leah Crane

Image
ESA/Gaia



NEIL BROMHALL/SCIENCE PHOTO LIBRARY

New beginnings

We can now create life without the need for sperm or eggs, with the power to revolutionise fertility. Should we, asks **Elie Dolgin**

YUE SHAO wasn't trying to create an embryo. But, a few years ago, working in a lab at the University of Michigan, he witnessed something mind-boggling. The cells he was working with seemed to assemble themselves into what looked just like an early-stage human.

"We were looking for something else," says Shao, a bioengineer now at the Massachusetts Institute of Technology – but "serendipity hit".

The idea that scientists could create the first steps towards human life is astonishing, but Shao's discovery wasn't the first. A year before he published his results in 2017, research by a team in Japan led to the birth of live mouse pups using eggs the team made from adult skin cells.

Discoveries like these are bringing us closer to solving some of the most intractable problems in reproductive biology and medicine. By recreating these first days of development in the lab, researchers are breaking open the black box of early pregnancy, a poorly understood and fragile time at which most miscarriages happen and fertility treatments fail.

Now 40 years after the birth of the first test-tube baby, the potential of these breakthroughs is heralding a new biological revolution, one that forces us to rethink what it means to reproduce and make a baby. And there's a lot to consider. Imagine being able to conceive a child from someone's skin cells, for instance – with or without their consent. Given the ability to make a human artificially, we need to decide whether we want to.

Already, some 1.5 per cent of all babies born in western Europe, North America and Australia are conceived using in vitro fertilisation (IVF). So making the spark of life outside the body is routine. But it is also unpredictable. So much is still unknown about why some embryos don't implant after transfer or, in both IVF and natural conceptions, what causes some to die while others keep growing. IVF also relies on prospective parents having viable sperm and eggs to work with in the first place.

Perhaps the boldest attempt so far at getting around that problem is to make sperm and eggs from totally unrelated cells in the body. Working with mice, Mitinori Saitou of Kyoto University in Japan and his collaborators took adult skin cells and reprogrammed them into stem cells, which have the potential to become any type of cell. They then turned these into either sperm or eggs. In 2016, they reported that they had fertilised some of these eggs with sperm from normal mice, and implanted the embryos into surrogates. Eight seemingly healthy pups were born. Then a year later, working with a team from the Crick Institute in London, they did the corresponding experiment using their lab-made sperm.

The potential for treating infertility is huge (see "Why make babies from skin cells?", page 32) but attempts at creating human sperm and eggs in the lab have so far produced only rudimentary precursors to these sex cells. For example, Azim Surani, a developmental biologist at the University of Cambridge's Gurdon Institute, announced in late 2017 that his team had managed to grow "primordial germ cells" – precursors of sperm and eggs – to the four-week mark. ›

WHY MAKE BABIES FROM SKIN CELLS?

Once it becomes possible to grow sperm and eggs in the lab from anybody's skin cells (see main story), people in wealthier countries with robust healthcare systems may even stop having sex for baby-making purposes, says Hank Greely at Stanford Law School in California.

"As people see that kids born this way don't have three heads and a tail, and as they begin to notice family members and friends who've had a kid with a serious disease that could be prevented," he says, "people will put themselves out for their children's health."

Greely envisions a future in which prospective parents would make an appointment at their local fertility clinic. A small sample of skin cells would be used to make stem cells from which sperm and eggs would be derived, before creating dozens, if not hundreds or even thousands of thriving embryos. After genetic screening, parents could pick the one they want to transfer.

It would put an end to the painful, invasive and expensive process of egg-retrieval during IVF. And those people incapable of making their own sperm or eggs could have genetically related children. So could same-sex couples.

But such technology also raises serious ethical questions. Although screening could rule out devastating genetic diseases, it would open the door to routine sex selection and other choices for non-medical reasons. And while it is already possible to access to this kind of information, its application is limited. Our rudimentary knowledge about how small genetic differences add up to something like IQ restricts things, as does the fact that egg-harvesting yields a maximum of a few dozen eggs per cycle.

"It's going to be very difficult to restrict that kind of information, and it might even seem perverse to try," says Anna Smajdor, a bioethicist and philosopher at the University of Oslo in Norway.

Next, he hopes to nurture these cells to eight weeks, the point at which they either goon to form sperm or eggs.

It is possible that if these were transplanted into the body, they would mature and restore fertility in otherwise infertile individuals, says Werner Neuhausser, a stem-cell biologist at Harvard University. But, he adds, "there's a whole other layer of safety issues that will have to be dealt with before this would ever enter clinical practice".

And we are still a long way from finishing the process in a lab dish.

One promising advance came earlier this year, when Evelyn Telfer at the University of Edinburgh, UK, and her colleagues cultured mature human eggs in the lab from a different type of stem cell found in ovaries. Telfer envisions using this technique to help women with cancer, where treatment can cause infertility. The idea would be to remove a piece of the ovaries before treatment, and to use it later on to make new eggs. It could also lead to "next-generation IVF", Telfer says, in which women would undergo a one-off surgical procedure to retrieve ovarian tissue, instead of successive cycles of hormones and invasive egg-harvesting.

> "It could lead to less invasive IVF or help women who are being treated for cancer"

Alternatively, we might not need to make eggs or sperm at all. Last year, a team led by Magdalena Zernicka-Goetz at the University of Cambridge coaxed two different kinds of mouse stem cells to assemble into a structure that, after three or four days in a lab dish, looked and behaved the same way as a natural embryo. "Superficially, they were very, very similar," says Sarah Harrison, who worked on the project as a PhD student.

Five months later, Shao's group published its creation of comparable "embryoids" made entirely with human stem cells (see image, opposite).

In both cases, the impetus for the research was a desire to understand the early stages of embryo formation, which are difficult to study inside the body – specifically, what happens after an embryo implants in the uterus and starts organising its cells into layers. Shao also envisions his embryoids providing a platform for screening drugs and environmental toxins to see whether they cause birth defects. Neither team is trying to make viable embryos.

Besides, after four or five days these embryo-like structures already look more like two-week-old natural human embryos. That means they have effectively skipped the earliest steps of development and missed the stage at which implantation is feasible.

So the only shot at viability that these lab-grown embryoids might have would be outside the womb. Until recently, that prospect would have been unimaginable, because no one had succeeded in nurturing human embryos in a dish past the implantation stage. But two years ago, separate teams led by Zernicka-Goetz and Ali Brivanlou, an embryologist at Rockefeller University in New York, described ways of getting human embryos to develop for up to two weeks after fertilisation. And they might have gone even longer were it not for the "14-day rule", a legal and regulatory line in the sand agreed by most countries engaged in research on human embryos.

That cut-off was chosen because it is the time at which a faint band of cells known as the primitive streak appears, a key developmental milestone for complex tissue formation. It is also when an embryo can no longer split into identical twins, and so it has been defined by some as the moment a distinct biological entity comes into being.

With that definition in mind, many scientists are now scrambling to figure out how best to apply the 14-day rule to research on embryoids like the kind Shao's team created – or even whether the rule applies at all. Last year, a team led by John Aach and George Church, geneticists at Harvard Medical School, gave these structures a name –synthetic human entities with embryo-like features, or SHEEFs – and called for a broad international discussion of ethical issues raised by their creation.

As bioethicist Sarah Chan at the University of Edinburgh points out, a mass of self-assembling stem cells doesn't have a clear day zero from which to start counting, so 14 days is meaningless. What's more, because SHEEFs don't develop along the conventional pathway, they may acquire morally concerning features long before the primitive streak is visible at 14 days. "We need to have this wide-ranging debate," Chan says.

As developments like these push how long we can grow embryoids in the lab, others are working away at one of the most daunting challenges in reproductive medicine – how to keep babies alive when they enter the world too early. According to David Adamson, a reproductive endocrinologist who runs Advanced Reproductive Care, a US-wide network of fertility clinics, this "will be

MICHEL ARTAULT/GAMMA-RAPHO/GETTY IMAGES

Louise Brown was the first child to be conceived using in vitro fertilisation, in 1978

exceptionally difficult, and not achievable in this century".

There are good reasons to try, though. Neonatologists are advised against trying to save the lives of babies born before 22 weeks because of limitations with existing resuscitation technologies. An artificial womb could change that.

Last year, fetal surgeon Alan Flake and his colleagues at Children's Hospital of Philadelphia described one such invention: a fluid-filled sac dubbed the Biobag. It kept lambs alive for about four weeks after they had been born at the equivalent of about 23 to 24 weeks in a human pregnancy, judged by lung development. Survival for premature babies is currently less than 50 per cent at that stage.

For the lambs, this and other systems, like the "artificial placenta" developed by George Mychaliska's team at the University of Michigan's Extracorporeal Life Research Laboratory, can serve as a bridge until the lambs are ready for artificial ventilators and eventually to transition to breathing on their own.

The next generation

"It does appear that the lungs are continuing to develop over time, and they're protected," Mychaliska says. In March, his team showed that the lambs' brains develop normally, too. "The goal is clinical translation in five years," he says. Human trials will initially include premature babies who have less than a 20 per cent chance of survival.

If one of these womb-like systems works for humans, it opens the door not just to sparking life in the lab, but keeping it alive entirely outside of the body. All these baby steps in our quest to improve the human condition could thus add up to the giant leap of making life from scratch. "My guess is this would be a major way of having babies 100 years from now," says Hank Greely, a bioethicist and lawyer at Stanford University in California. "Once you get 50 or 60 years out, the sky is the limit with biology."

Others are less bullish. "A lot of things have to go very, very wrong – and have been very wrong for a while – before that would seem like a good idea," says Gigi Gronvall at the Johns Hopkins Bloomberg School of Public Health in Baltimore, Maryland.

And Jeantine Lunshof, a bioethicist at the University Medical Center Groningen in the Netherlands, says: "Given the ease of making babies, in general, I do not see any need for it, nor arguments to support such an endeavour."

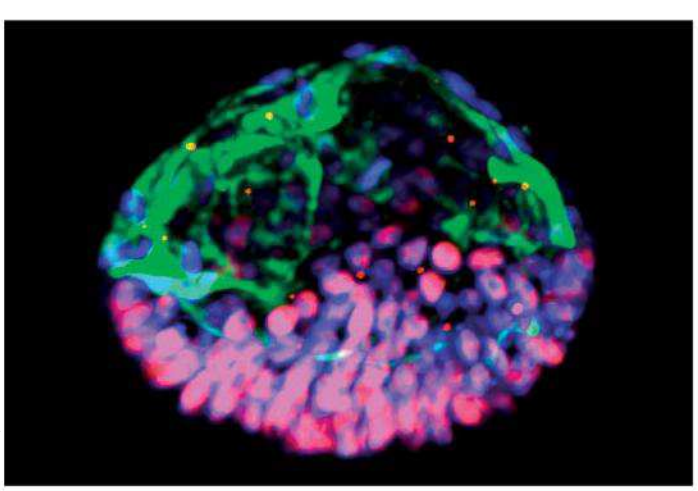
Yet similar things were once said about IVF: it was too dangerous, an unnatural and immoral abomination. Then came the birth of the first "test-tube baby" Louise Brown in 1978. An estimated 7 million have followed since. Now the fertility technique is practically routine, and few outside certain religious circles continue to debate its merit.

A similar acceptance could prevail for the next generation of assisted-reproductive treatments.

One reason to continue towards the goal of a complete from-scratch baby would be protection against some kind of environmental catastrophe or nuclear disaster. Think *Children of Men* or *The Handmaid's Tale*. "If the human race as a whole were seriously endangered, and if our reproductive abilities were seriously compromised, we might have to manufacture human beings," says Ronald Green, a retired ethicist from Dartmouth College in Hanover, New Hampshire.

More likely, says Anna Smajdor, a bioethicist and philosopher at the University of Oslo, Norway, the ability to build human life from scratch would occur more as an after-effect than as a deliberate goal of reproductive research. As new technologies develop for bona fide medical reasons – treating infertility, preventing the transmission of genetic disease, saving the lives of premature babies – "you'll get this creep," she says.

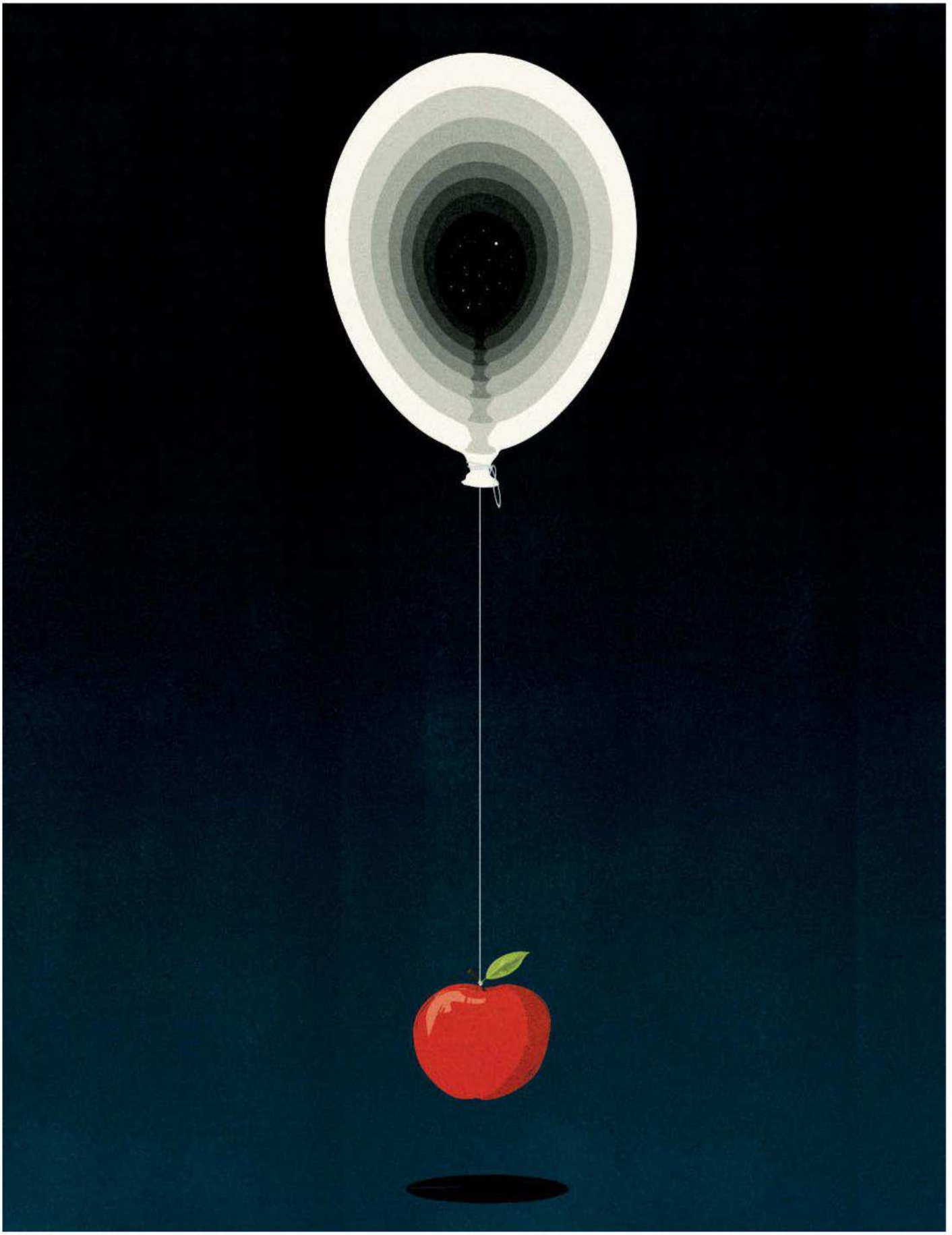
Whatever the driver, it is undeniable that a huge biological shift is under way. Still, if experiments like Shao's tell us anything, it's that whether you are doing it in the lab or the old fashioned way, when it comes to the spark of life, you can never predict the outcome. ■



YUE SHAO, UNIVERSITY OF MICHIGAN

A five-day-old human embryoid , created from stem cells with no sperm or egg

Elie Dolgin is a science writer in Somerville, Massachusetts



ANDREA UCINI

Perfect disharmony

Gravity is stalling attempts to unify nature's forces. Is peaceful cohabitation a more realistic goal, asks Anil Ananthaswamy

GRAVITY just doesn't play ball. It is the odd one out, the square peg in the round hole. It is a party pooper, a stick-in-the-mud, an old fuddy-duddy: unreformed and, seemingly, unreformable.

Its crime, in the eyes of many fundamental physicists, is that it refuses to kowtow to quantum theory's claim to be the one true theory. Our understanding of every other phenomenon under the sun – and indeed the burning of the sun itself – is underwritten by models with quantum particles at their heart. Gravity is the eternal refusenik.

Our current picture of gravity is painted by Einstein's general theory of relativity. Einstein is one of many who have attempted, forlornly, to broker an understanding between the two theories. But gravity has resisted any attempt to force it into a quantum straitjacket.

Now a bunch of physicists are advocating a gentler approach: let gravity be gravity, and look instead at how quantum theory might change its ways to accommodate it. Their thinking is that perhaps then quantum theory and gravity might join, if not in perfect union, then at least in amicable cohabitation. With a first few theoretical successes already ticked off, now it is time to put the idea to the test.

The cosmologist John Wheeler came up with probably the best way of visualising how general relativity works: "space-time tells matter how to move; matter tells space-time how to curve", he wrote. A large agglomeration of matter (Earth, say) curves space-time around it. Other matter (a falling apple, for example) moves along those curves and so feels gravity.

The other three forces of nature, electromagnetism and the strong and weak nuclear forces, are all transmitted very differently, by the exchange of quantum particles. General relativity works very well on scales where classical physics rules the roost, with large masses and large distances. It predicts surprising effects, confirmed by experiment, such as the bending of distant starlight as it passes the sun, caused by its warping of space-time.

The problem comes when the matter causing space-time to warp is made of quantum particles. Quantum theory is a probabilistic theory: it doesn't tell you definitively how things are now, just how they are likely to turn out when you make measurements. That unleashes mind-boggling apparitions such as Schrödinger's cat, seemingly both dead and alive until you look to find out.

"Gravity refuses to kowtow to quantum theory's claim to be the one true theory"

Unsettling it may be, but this fuzziness has been verified to astonishing precision in the lab. One consequence is that quantum particles don't appear to have definite positions before you measure them. But if they don't have definite positions, you can't predict how they will curve space-time. So with current theories as your starting point, you can't make a workable model of quantum gravity. And that means in situations where both gravitational and quantum effects hold sway, such as the big bang or within black holes, answers will elude you.

It is a roadblock with no obvious diversionary route – and that bothers a lot of physicists. "One expects some kind of fundamentally unified description of nature," says Daniel Sudarsky at the National Autonomous University of Mexico. Whole research programmes into areas such as string theory and loop quantum gravity aim to find a way through, but so far have had little success.

We have been working on the problem for some time. In fact, back in the 1960s, physicists came tantalisingly close to finding a fix that combines general relativity with quantum mechanics. It is called the semi-classical Einstein equation.

Einstein's original theory consists of a series of equations in which the left-hand side represents the curvature of space-time. The right-hand side, meanwhile, encapsulates how the distribution of matter and energy changes continuously over time, creating that curvature. In the equations, this distribution appears as a solidly classical mathematical term known as the energy-momentum tensor. In the semi-classical Einstein equation, this is replaced by a quantum "expectation value" that represents the average matter distribution you would ›

expect to obtain from many measurements. It is the equivalent of shrugging and saying, we don't know exactly where the matter is, but this is our best guess.

This trick allows matter to remain quirkily quantum while its gravitational effects are predictably classical. It has proved immensely useful in many astrophysical calculations. Stephen Hawking used the method in the 1970s, for example, in his seminal work showing that black holes emit Hawking radiation. "As long as we don't have fully quantised gravity, which we might never have, this is a very, very powerful tool," says Lajos Diósi of the Wigner Research Centre for Physics in Budapest, Hungary.

"Nowhere are the problems of quantum theory more acute than at the big bang"

Powerful – but defective. The thing is, the semi-classical Einstein equation can't cope with that all-important moment when you measure the position of quantum matter, "collapsing" it to a localised point in space and time. This abrupt jump causes the equation to blow up, with its two sides providing different answers – a mathematical nonsense.

Similar defects plagued Diósi and, independently, Roger Penrose at the University of Oxford in the 1980s, when they attempted to combine quantum mechanics and Newtonian gravity. Newton's simpler picture of gravity has been superseded by general relativity, but is still a good description for objects moving at significantly less than light speed.

But all these semi-classical theories ended up having discomfiting effects. They predicted, for example, that even something as classically dependable as the moon could end up in a quantum "superposition" state with half its mass in one place and the other half elsewhere – a truly loony version of Schrödinger's cat. Similar superpositions could infect space-time itself, creating a new layer of confusion that might, in theory, enable signals to travel faster than light speed. Not only that, but the equation resulted in a breakdown of the quantum world's predictably probabilistic nature, going against decades of experiment.

As practical descriptions of reality, then, these hybrid theories seemed implausible. Penrose was among the first to suggest the blame for this impasse lay not with gravity, but with quantum theory.

Specifically, it came from that moment of collapse. The standard interpretation is that the act of measurement causes the quantum world to shift into classical certainty. But this leaves many unanswered questions, such as how big a measuring device must be to collapse a quantum state, and whether the process requires a human observer or some other form of consciousness.

Nowhere are such questions more acutely unanswerable than at, and soon after, the big bang. Collapsing quantum states in the infant cosmos are thought to have played a pivotal part in its subsequent development, determining how stars, galaxies, planets – everything, in fact – eventually formed. But how did they collapse with nothing around to measure them? "In ordinary quantum mechanics, measurement involves an external device," says Sudarsky. "What's playing this role in cosmology? If I don't want to invoke God or something external to the universe, which I don't, I have no place to locate this measuring device."

In recent years, Sudarsky and others have begun working with a mathematically equivalent alternative to standard quantum theory known as the spontaneous collapse model (*New Scientist*, 16 July 2016, p 30). This contends that quantum states collapse randomly without the need for an explicit measurement. The average time it takes for a single quantum particle in a collection to collapse is very long – about the age of the universe – but if one goes, they all go. As an object's size and the number of particles it contains increases, the likelihood grows – indeed reaches certainty – that the quantum state of the entire object will collapse. This explains why microscopic quantum systems remain quantum, while macroscopic objects have definite, classical forms.

Bridging the divide

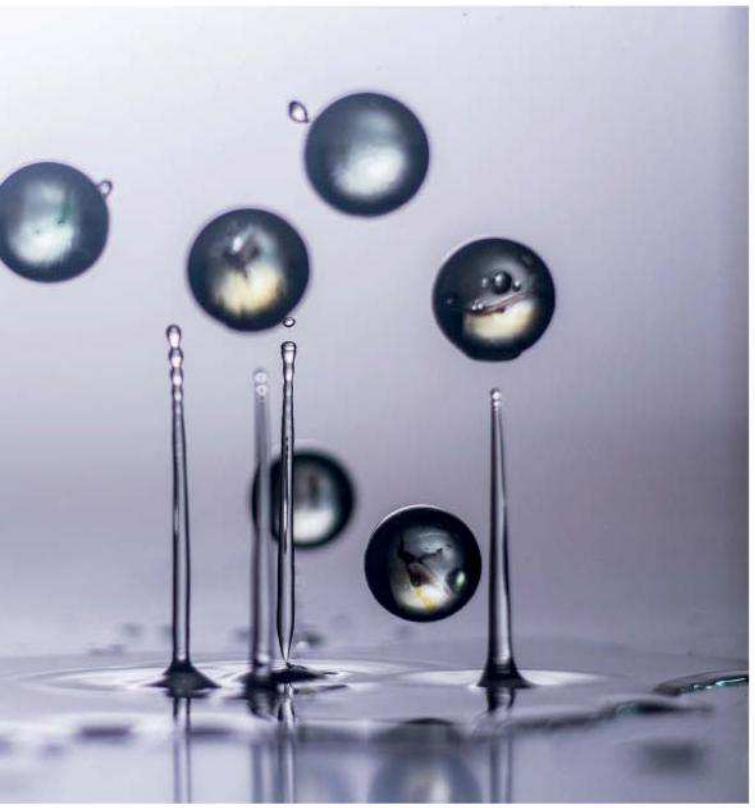
The first collapse theory, called Ghirardi–Rimini–Weber or GRW theory, was formulated in 1985. It didn't catch on, partly because of entrenched views about the correctness of standard quantum mechanics, and also because the equations didn't explain why spontaneous collapse happens. "They are ad hoc and I understand when people say that they are ugly modifications," says Antoine Tilloy at the Max Planck Institute of Quantum Optics in Garching, Germany.

So it certainly never occurred to anyone that collapse theories might help bridge the gap between quantum theory and gravity. "People could have tried this 35 years ago, if they had been more open to alternatives to standard quantum theory," says Maaneli Derakhshani of Utrecht University in the Netherlands.

ANURAG DAS/EYEEM/GETTY

In 2013, Derakhshani made the first attempt to incorporate GRW collapse theory into equations seeking to combine quantum theory and Newtonian gravity. He found a marked improvement. The quantum world remained fuzzy and quantum just as experiments required; and the weird Schrödinger's cat states for macroscopic objects such as the moon went away, as common sense demanded.

But the theory still allowed signals to travel faster than light, a no-no for those who believe in standard ideas of cause and effect. That problem has only been solved over the past few years by Tilloy. Working first with Diósi and then on his own, he incorporated a slightly different collapse model into a theory of semi-classical Newtonian gravity. This model calls individual collapse events "flashes", and proposes that they happen randomly at specific points in space-time, causing matter to end up in definite positions and so give rise to gravity. Space-time itself remains classical and can never enter into a



Gravity works: why change a winning formula?

quantum superposition of states, removing the potential for faster-than-light influences. "This is what saves you," says Tilloy.

It is still early days, he cautions: this work is just a proof of concept showing that you can formulate semi-classical theories of gravity without all the paradoxes. "Basically, my main objective was to destroy the counterarguments," he says.

Sudarsky thinks that Diósi and Tilloy's work is an important step. But he agrees there is more to be done, not least in moving beyond Newtonian gravity to the Einsteinian picture. "Now the question is how to make that all compatible with general relativity," he says.

That's just what he and his team are now attempting to do, using yet another variant of the spontaneous collapse model. So far, they have shown how semi-classical gravity can describe matter and its effects on space-time before and after collapse. They are also making significant progress with the mathematics at the actual point of collapse.

One of the most appealing aspects of such work is the growing potential for experiments to confirm or deny its results. Take collapse theories themselves. If spontaneous collapse really occurs, we should be able to see it happening. Double-slit experiments, for example, are used to test the quantum nature of matter: single quantum objects pass through the slits, creating an interference pattern that shows they are in a superposition of being in two places at once. We could see if molecules larger than a certain size collapse spontaneously into a classical object by pushing larger and larger molecules through double slits, watching for the point at which the quantum interference stops. "Until five to 10 years ago, it was absolutely impossible to propose any experimental tests," says Diósi. "Now, the situation is completely different."

> **"If gravity is ultimately a quantum force, it should create entanglement"**

Then there is the gravity side of things. If gravity is ultimately a quantum force, it should do something that the other forces can do: create entanglement. This is when the state of particles that have interacted via a quantum force remain forever intertwined, however far apart they might subsequently be.

In November 2017, Sougato Bose of University College London and his colleagues proposed an experiment to test gravity's entanglement-giving powers. The idea is to let two masses, each of them in a separate quantum superposition of states, fall freely. The experiment is designed such that the only possible interaction between these masses as they fall is gravitational. At the end, you can test whether the quantum states of the two masses are entangled with each other. If they are, gravity must be a quantum force, and there must be an as-yet-unknown route to describing it with quantum theory. "If that's the case, then we are toast," says Tilloy. Alternatively, if gravity cannot create entanglement, semi-classical gravity remains a viable proposition.

Tilloy's own work suggests other experimental tests. Usually, the strength of Newtonian gravity falls in step with the square of the distance from the source. Tilloy's equations predict that this standard force law will break down at length scales of about 10^{-10} metres, around the size of an atom. "It's not super, super small. But still, it's very small for gravity," says Tilloy. "The behaviour of gravity beyond micrometres is not known." In the future, more sensitive experiments should be able to detect any deviation.

Carlo Rovelli at Aix-Marseille University in France thinks such experiments will only show us we still need a quantum theory of gravity. According to general relativity, the dynamics of gravity are not unlike those of other fields, such as the electromagnetic field. "I see no reason why it should not behave like any other dynamical entity in nature, and be a quantum field," says Rovelli. "I bet 99 to one that the outcome will be consistent with gravity having quantum properties."

Despite working on theories of semi-classical gravity himself, Sudarsky sounds a similarly sceptical note. At its most fundamental, he thinks, gravity probably is quantum mechanical, and when it emerges from a deeper, as-yet-obscured layer of reality, we get Einstein's classical space-time.

All the researchers are well aware that they are treading on uncertain ground in their search for a theory of semi-classical gravity. But the potential prize is too great to ignore: gravity that works as Einstein predicted, but also in the quantum world. A square peg sitting comfortably in a round hole. "It may not have anything in common with reality, but we must explore," says Diósi. "It might have some seeds of truth." ■

Anil Ananthaswamy is a consultant for *New Scientist*

Can animals keep the doctor away?

We are increasingly looking to animals as therapy for everything from depression to autism, **John Bradshaw** tells Nic Fleming

Daniel is framed in silhouette as he gazes out at the passing clouds through an aeroplane window. The picture went viral on social media in October 2016. It probably helped that Daniel is a duck, or more specifically, an emotional support duck. His owner says he helps her cope with post-traumatic stress disorder.

In the US, an animal can often board a flight as long as a doctor has signed a letter stating it helps its owner deal with a medical condition. Delta Air Lines carried 250,000 such animals in 2017 – up 150 per cent on 2015. Most are dogs, but the increasingly exotic menagerie includes pigs, hamsters and peacocks.

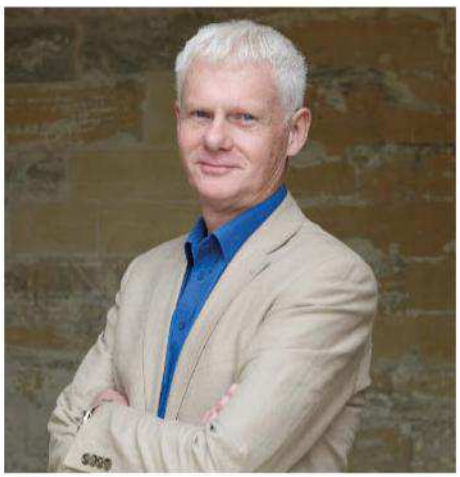
A recent rise in media reports about emotional support animals has brought me to John Bradshaw. He studies anthrozoology, or the ways in which humans and animals interact, at the University of Bristol, UK. I have come to find out if animals really can help people with mental illness, and if so, how?

He shows me into a cosy attic study in his home, its shelves filled by books with titles including *What It's Like to Be a Dog* and *Feng Shui for Cats*. Alongside them sit copies of Bradshaw's own works *Dog Sense* and *Cat Sense*, which have together sold more than 400,000 copies. Here, Bradshaw tells me that there is almost no evidence for the claims made about animals and mental health, not just for emotional support animals, but virtually all forms of animal therapy – and even pets.

This might seem surprising given that belief in the positive effects of animals is widespread. A 2014 survey found that 97 per cent of US family doctors believed owning a pet has health benefits. It has become routine

SUEMACK/GETTY

Many animals, including guinea pigs, are regular visitors to nursing homes



GERAINT LEWIS/EYEVINE

DAVID JONES/PA ARCHIVE/PA IMAGES

John Bradshaw (far left) studies how we interact with animals, including whether dogs can motivate children to read

to take all kinds of animals, including donkeys, into nursing homes, prisons, schools and hospitals. UK charity Pets as Therapy has more than 4000 dogs on its books for just this purpose. And about 20 animals, including Lilou the tutu-wearing pig, roam San Francisco International Airport to calm flyers' nerves.

"Studies do suggest associations between dog ownership and good health," says Bradshaw. "The real question, however, is whether they show cause and effect." For example, a study in California last year found that children in families with pets were healthier and more active than those without. However, the dog owners were also 3.5 times more likely to own their own home. The researchers concluded the positive effects were the result of socio-economic factors.

Cheering effect

What little research there is into the healing powers of animals suffers from similar problems. People confuse feeling good in the presence of animals with long-term clinical benefits, says Bradshaw. "When you stroke a pet, your oxytocin and endorphin levels go up, your blood pressure comes down and your heartbeat gets more regular," he says. "But there's no evidence that this translates into anything that lasts even a couple of hours, let alone a lifetime."

A 2017 review found that despite widespread use of animal therapies, research into efficacy is "in its infancy", and evidence-based ideas for how they might work are lacking. For example, some studies have found the presence of animals can have a cheering effect in hospitals and care homes. But this might be because animals boost the mood of staff and make a normally sterile environment seem more pleasant, says Bradshaw.

Other possible explanations include the finding that people are rated as more trustworthy when with animals. Alternatively, the fact that an animal in a therapeutic setting is accompanied by a human may suggest that the benefit is in improving social interaction.

Despite the lack of evidence, animal therapy is touted as a treatment for serious conditions, including PTSD, depression and addiction. It is also big business. A session of dolphin therapy, where people come into close contact with a dolphin in a pool, can cost upwards of £600 per hour.

The idea that animals offer health benefits can be traced to the 1960s, when New York psychotherapist Boris Levinson found that some children with communication problems opened up more in the presence of his dog, Jingles. There is some evidence that animals benefit children with autism. Bradshaw's own research shows that playing with a dog helped some autistic children learn to read. Even in this area, though, studies vary in the forms of treatment and outcomes measured, and it is often unclear whether playing with animals is any more effective than other enjoyable activities.

How about dolphin therapy, I ask. "There's a huge amount of mumbo jumbo surrounding it," says Bradshaw. "It might be fun, but there are no independent studies that have shown any beneficial effect whatsoever."

None of this is to deny that animals might help people. But without research that controls for other effects, we can't know which animal in what setting might be best. The lack of solid evidence means, for example, that the US Department of Veterans Affairs has refused to cover the cost of service dogs for veterans with PTSD.

There is another reason to be sceptical that goes to the heart of Bradshaw's motivation to understand human-animal interactions. He is a director of the Universities Federation for Animal Welfare and says that many people don't understand the responsibilities involved in ensuring animals in their care have a good life. "There is a danger that if doctors encourage people to get pets for health reasons, not only will this approach fail but it may also result in poor animal welfare."

And as for dolphins, they are wild animals, even if trained. The charity Whale and Dolphin Conservation has called for a ban on all dolphin therapy, on the basis that it is harmful for both the animals and people.

That might be true for other species, too. There is some research to suggest that in certain situations animals can increase a person's distress. Hal Herzog, a psychologist at Western Carolina University, has argued that emotional support animals might prolong an individual's psychological issues by enabling them to avoid or delay dealing with their problems in other ways.

Bradshaw's no-nonsense attitude has led some animal lovers to see him as "anti-pet". But a glance around his home belies that notion. There are pictures of past pets and other animals everywhere. He and his wife Nicky no longer have animals because one of their grandsons has an allergy, but they hope to have them again some day.

"I'm far from anti-pets," Bradshaw says. "It's part of being human. What I am is pro-realism. If people understand their pets better, both they and their animals will benefit." ■

Nic Fleming is a writer based in Bristol, UK. **John Bradshaw**'s latest book is *The Animals Among Us: The new science of anthrozoology* (Allen Lane)

Computer says *"no comment"*

Artificial intelligence is by its nature inscrutable – how can we learn to trust it with our lives, asks **Timothy Revell**

IT SHOULD not have taken Cambridge Analytica to remind us that algorithms can have an insidious influence. Arguments rumble on about what privacy rules were broken, if any, and whether the company's mass profiling of Facebook users swung the 2016 US Presidential Election and the UK's Brexit vote. What we are clear on is something we had been warned about: give an algorithm a load of data about ourselves, and in return it assumes power over our lives.

Facebook and Google's artificial-intelligence algorithms, learning from the data we feed them, already control what we read on the web. Similar machine-learning algorithms determine the interest we pay on a loan and, in some places, the chances the police will stop and search us on our way home. Soon they could be driving cars, helping to make life-or-death decisions in the operating theatre and deciding fates on the battlefield.

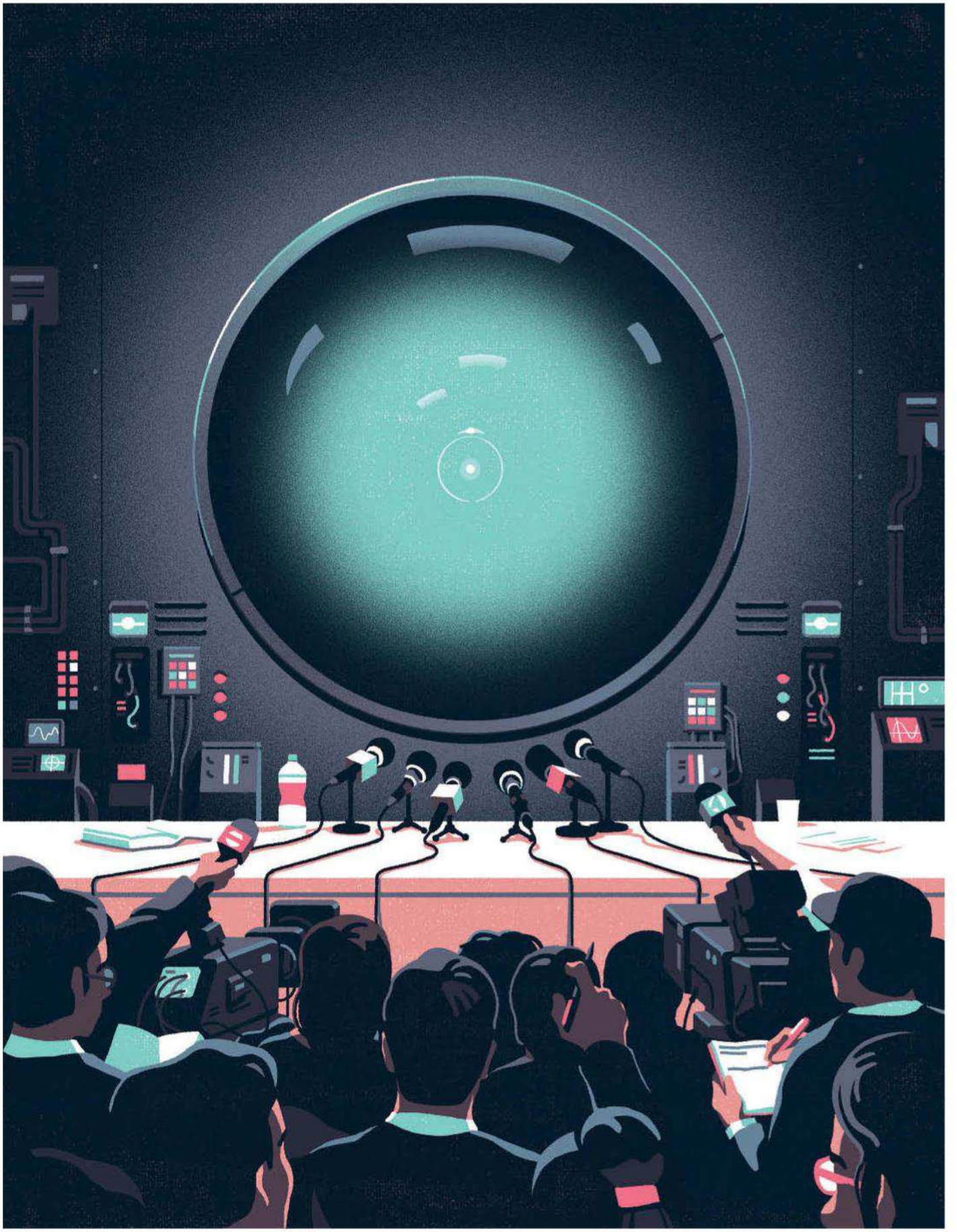
Sometimes these algorithms blunder, discriminate, or overstep the line – so we need to be able to hold them to account. The European Union has fired the first salvo, giving its citizens the right to an explanation for why an algorithm did something that affects their lives. The trouble is, the techniques behind the AI boom are by their very nature a black box. Even the people who create these machine minds don't understand their reasoning.

That's alarming enough given their current reach. But if AI is going to fulfil its promise and take an ever-more important role in society, we need to find a way to trust it. The question now is: how?

Algorithms are not intrinsically mysterious. They are simply sets of instructions that tell a computer how to perform a task. Even so, many in use today are proprietary because the companies behind them want to protect their intellectual property – and that has already raised some troubling scenarios.

Perhaps the most notorious case is that of Eric Loomis. In 2013, he was convicted of fleeing from the police and operating a vehicle without its owner's consent in La Crosse, Wisconsin. Sentencing him to six years in prison, the judge cited the "high risk" Loomis posed to the local community – a risk determined in part by his score on the COMPAS assessment, a proprietary algorithm designed to predict the likelihood that someone will reoffend.

Loomis challenged the ruling on the grounds that the judge, by considering the outcome of an algorithm whose workings are not transparent, had violated due process. But in June 2016, the Wisconsin Supreme Court rejected his appeal – a verdict handed down just a month after the non-profit news organisation *ProPublica* discovered that the COMPAS system was twice as likely to incorrectly predict that a black person would reoffend than a white person. ›



BRUNO MANGYOKU

Take back control!

For the first time in two decades, the European Union is sprucing up its data protection laws. From 25 May 2018, the General Data Protection Regulation will come into effect across the EU. Here's what its citizens will gain.

Consent Companies will no longer get away with a check box and thousands of pages of terms and conditions. They will have to make it clear how they will use your data, and who they will sell data to, in a concise manner. You will be able to withdraw your consent at any time.

Freedom Rather than your data being tied into one platform forever, you will be able to demand that a company extracts all the data they hold about you and sends the information to another company. You will also be able to delete the original records, all free of charge.

Explanation You will have to be informed when automated decisions are made that affect your life, and you can challenge the outcomes. If things go wrong, companies will have to give you meaningful information about the decision. Some call this a right to an explanation, but it is not clear how informative the explanations will be.

Equivant, the company that developed the system, disputes that analysis. But COMPAS is not the only algorithm under scrutiny. In fact, examples of algorithmic discrimination have stacked up over the past few years, and it's not hard to see why it happens. If you feed an algorithm data from the real world, it will reproduce the biases that already exist there.

Now governments are under pressure to ensure that algorithms are fair and transparent. Provisions for algorithmic accountability are baked into the EU's wide-ranging General Data Protection Regulation, which comes into force next month (see "Take back control!", left). It is a laudable aim. But there are question marks over whether it is even possible.

In many cases, the companies involved could plausibly be forced to give up their code to a government watchdog, which would go through it line by line to understand the decisions it makes. But for the growing number of systems reliant on machine learning, the collection of techniques underpinning the most sophisticated AIs today, that would be impossible.

"These things think in a very foreign way," says David Gunning at the US Defense Advanced Research Projects Agency (DARPA), which is interested in AI's potential to supercharge reconnaissance, among other things. "They use bizarre mathematical logic that it is very alien to us."

With traditional computer programs, the machine gets line-by-line instructions. With machine learning, however, the computer must work out how best to solve the problem. The result is a machine that essentially programs itself.

Imagine instructing a robot to make soup. The conventional approach would be to write out a precise recipe for SoupBot to follow. *First peel the onion, then cut the onion.* But a SoupBot based on machine learning would instead work out what to do on its own, perhaps by watching thousands of videos of people making soup and trying to come up with its own soup-like recipe, or by attempting to make soup again and again and learning from feedback on the results of each attempt.

In the case of SoupBot, the conventional approach would be most efficient. But simple recipes don't exist in many scenarios. There isn't one for recognising words in a sound recording, say, or for verifying a face to unlock a phone. And this is where machine learning comes into its own. By working out how to quickly spot patterns in vast amounts of data, an AI can master exceedingly complex tasks.

Open the box

This is usually thanks to an underlying technique called deep learning – one of the most successful ways to get machines to learn for themselves. It involves a vast, layered network of connections, inspired by neurons in the brain. With every example the system sees, and sometimes there are billions, the network tweaks the pattern and strength of its connections to reflect the new information, in a similar way to how neurons in the brain reinforce connections when learning something new.

The most famous deep-learning system is AlphaGo, an AI created by Google-owned DeepMind for playing the ancient Chinese board game Go. It had no strategies directly programmed into it, not even the rules of the game. But after viewing thousands of hours of human play, and then refining its technique by playing against itself, AlphaGo became the best Go player in the world.

"Forcing AIs to explain themselves could in many cases hold them back"

ISTOCK / GETTY IMAGES PLUS

Would you trust an AI to operate on you?

CHRISTIE HEMM KLOK/THE NEW YORK TIMES/) REDUX / EYEVINE

The first death by self-driving car has highlighted the legal questions raised by AI

Just like our brains, however, deep learning is deeply mysterious. Once the network is up and running, not even its creators can know what it is doing. For a long time, this black box problem was AI's dirty little secret. But these days it is out in the open, and researchers are trying to figure out the best solution.

For Regina Barzilay at the Massachusetts Institute of Technology, the answer lies in making AIs that can explain themselves. "Transparency helps build confidence," she says.

The first steps in that direction have already been taken. A team led by Trevor Darrell at the University of California, Berkeley, took a machine-learning system designed to identify bird species in photographs and bolted on another with the sole purpose of explaining how it arrives at its conclusions. For example, it correctly identified a picture of a white pelican because, it explained, "this bird has a white body, long neck, and large orange bill".

Barzilay and her team have done something similar in a medical setting, working with an AI designed to predict the type of cancer a person has from their medical records. Here, the explanation doesn't come in the form of a line of text, but in a nod to the parts of the report that led the AI to its conclusion.

Training the system wasn't easy: the team had to manually annotate thousands of reports, which were then fed into the algorithm to teach the system to process documents itself. But for Barzilay, the efforts will be worth it if her system can convince doctors that AIs can improve diagnosis. "AI is not used very much in medicine yet, because for doctors it is a foreign tool," she says. "They need it to explain why it makes predictions."

But prising open the black box in this way means making trade-offs, says Gunning, who leads DARPA's multimillion-dollar Explainable AI project. "The highest-performing system will be the least explainable," he says. This is because machines can create far more complicated and intricate models of the world than most humans can comprehend. Ultimately, if this technology is going to be most useful when it goes beyond what humans can do, forcing it to explain itself could in many cases hold it back.

But perhaps AIs don't have to explain themselves. "You don't have to crack open the black box to demonstrate fairness," says Chris Russell at the Alan Turing Institute in London. Instead of explaining why something happens, Russell and his colleagues use a "counterfactual" approach: they tweak the inputs to demonstrate what would have to change to alter an AI's decision. Say you were denied a loan, for example, you might find that if your salary were £30,000 rather than £25,000, the loan would have been approved.

"What people want is to understand the decision, so that they can either challenge it or have an indication of what would need to change to alter it," says Sandra Wachter at the Oxford Internet Institute in the UK, who worked with Russell to develop the technique.

Anupam Datta at Carnegie Mellon University in Pittsburgh, Pennsylvania, is using a similar approach to root out biased and discriminatory AIs. He and his colleagues propose testing them by tweaking inputs such as gender or ethnicity, and seeing whether the outcome changes. For example, if two people who differed only in ethnic origin weren't given the same likelihood of committing a crime in the future, that would indicate that the system may be biased.

Leaps of faith

The technique could form part of a certification system that every algorithm must go through before it is released, says Datta. "It can also be used on systems already in use," he adds, so biased AI can be exposed and challenged under relevant laws.

The trouble with the counterfactual approach is that it works best when reasonably simple bits of information are used to make a decision – a few personal details, say. It is a lot trickier when there is an almost continuous stream of data to analyse, as in the case of an AI behind the wheel of a self-driving car.

But some argue that even in life-or-death scenarios, we may not always need AI to show its workings. Last year, Kilian Weinberger of Cornell University asked his audience at the Neural Information Processing Systems conference in Los Angeles to imagine they had a heart disease that required surgery. There is a 10 per cent fatality rate if a human performs the procedure, but only a 1 per cent fatality rate if a robot does it. If the surgeon makes a mistake, they can explain it: sorry, I cut the wrong artery. But the robot can't because it uses machine-learning software. "Which one would you pick?" asked Weinberger.

Assuming the error rates are accurate, you would trust the robot, he argued. We take these leaps of faith all the time. We have been using aspirin for thousands of years, initially in the form of willow bark, but didn't understand how it worked until the 1970s. "You don't have to understand why a drug works to get it approved by the regulators," said Weinberger. "You just have to show that it does."

That said, it is not only a trust issue – it is also about legal responsibility. The death of a person hit by a self-driving car in Arizona in March has brought into sharp focus the question of how an AI can be held to account in the same way a human would be. This stuff is no longer hypothetical.

As the Cambridge Analytica story shows, the stakes are high for all of us. "Society needs to understand what's happening, so that we can ask about what kind of world we want," says Adrian Weller, at the University of Cambridge.

And there's the rub. If AI is to enhance our lives rather than dictate them according to arbitrary, incomprehensible rules in some sort of Kafkaesque scenario, we need to be clear about exactly what we expect of it. ■

Timothy Revell is technology editor at *New Scientist*

Your mind is not an iceberg

Challenging the entrenched idea that our minds run "deep" will take strong, new arguments. **Anil Ananthaswamy** explores

JAMES FASSINGER/STOCKMO/ALAMY

The Mind Is Flat: The illusion of mental depth and the improvised mind by Nick Chater, Allen Lane

"THERE is no inner world. Our flow of momentary conscious experience is not the sparkling surface of a vast sea of thought – it is *all there is*." And with this dramatic claim, Nick Chater sets out to convince us that the ubiquitous feeling our minds have depth – that our actions and behaviours can be explained in terms of something more within – is misplaced and wrong.

In *The Mind Is Flat*, Chater begins by asking us to think about the suicide of the hero in Tolstoy's *Anna Karenina*. We could make sense of Karenina's actions based on what we know of her character, but Chater says that we would be making up a story because she is fictional and so has no inner life.

Real humans, he argues, also have no inner lives, and any justifications for our actions are similarly concocted. "The very idea that our minds contain 'hidden depths' is utterly wrong," says Chater, a professor of behavioural science at Warwick Business School in the UK, adding: "There are no pre-formed beliefs, desires, preferences, attitudes, even memories, hidden in the deep recesses of the mind."

It is a controversial argument, going against our intuition that there is more to our minds than meets conscious awareness. It also goes against current thinking in psychology and neuroscience. Chater knows this, admitting that he is disquieted by his own ideas.

Whether you agree with him or not, Chater writes passionately and evocatively. His case is that our sense of having desires, motivations and fears that drive our actions is due to the fact that thoughts are made up on the fly: there is no place in the mind where they are stored . "Thoughts, like fiction, come into existence in the instant they are invented, and not a moment before," he writes. "The stories we tell to justify and explain our own and others' behaviour aren't just wrong in detail – they are a thoroughgoing fabrication from start to finish."

He draws on psychology, neuroscience and AI to bolster his case. His favourite examples draw on visual perception, showing that our idea of a complex, colourful visual field in front of us is an illusion, the careful fabrication of an artful brain. For Chater, the sense of mental depth is also neural chicanery.

"Thoughts, like fiction, come into existence in the instant they are invented, and not a moment before"

He also looks to the 1980s, when researchers thought they had cracked AI when they built expert systems, software specific to a domain such as health. They encoded human knowhow into a "knowledge base", while another piece of software (an "inference engine") used the knowledge to reason about problems.

Expert revolution

The pioneers of AI seemed to be duplicating the workings of the human mind. "They took it for granted that the thoughts that we consciously experience and can put into words are drawn from a vast sea, or web, or database of similar, pre-formed thoughts, which we are not currently consciously experiencing," explains Chater. "Behind each expressed thought lies, supposedly, a thousand others beneath the surface."

Expert systems were going to revolutionise AI. They never did. And there's a lesson in this: for Chater it means that our understanding of human minds is also wrong. We do not possess some hidden knowledge base we tap into for reasoning, to make judgements and to act; consequently it is wrong to think we can peer inside our minds to explain ourselves. "In reality, when we decide what to say, what to choose, or how to act, we are… literally, making up our minds, one thought at a time."

But Chater is setting up a straw man. Not all of us feel we are simply accessing or reasoning using a database of preformed answers to questions. And neither does computational neuroscience argue for such a database: in fact, we don't really know the algorithms the brain uses to reason. And that is no argument for or against depth.

Chater acknowledges that the human mind is unprecedented in both its complexity and its ability. To explain its powers, he suggests that at any moment the brain's networks of neurons are engaged in a "hugely complex cooperative computation", a process of which we only become aware through the networks' output – for

example, a thought – but without ever knowing the inner workings.

In itself, this claim is not controversial: conscious awareness is not considered to be everything that the brain does, and we may never be privy to its deeper goings-on. But Chater will not allow himself to imagine that thoughts "can be divided in two as the waterline splits an iceberg: the visible conscious tip and the submerged bulk of the unconscious, vast, hidden and dangerous". There is no iceberg.

To me, all this seems to hinge on semantics. Take what happens when he writes that there "is just one type of thought, and each… has two aspects: a conscious read-out, and unconscious processes generating the read-out". Surely if there are unconscious processes, even those we can't access, that is evidence of mental depth? Or at least, something more than an on-the-fly model?

What do these processes depend upon? How do they give rise to our brain's capabilities? Chater argues that our brain improvises moment by moment, and that these improvisations build on the "fragments of past improvisations". He accepts that each of us is "a rich store of distinctive past experience", and that there are "layers of precedents – the successive adaptation and transformation of previous thoughts and actions to create new thoughts and actions".

Is there more going on inside your head than you're aware of?

All of this sounds a lot like "the brain has memory and learns", and that this memory and learning influences subsequent behaviour. Some computational neuroscientists would call that hierarchical deep-learning, even if we don't fully understand how the brain pulls it off.

Humans are smart in part because we think imaginatively and in metaphors, says Chater, referring to cognitive linguist George Lakoff's seminal book, *Metaphors We Live By*. But Lakoff and others have also argued that metaphorical thought is rooted in our bodies – a form of embodied cognition that is nothing if not a deep kind of mind. Chater, however, gives short shrift to this idea and to all deep-mind aspects of our being.

His flat-mind hypothesis reads like a makeover of behaviourism, the early-to-mid 20th-century philosophy that privileged outward behaviour over inner subjective states and, in its extreme form, even denied the existence of any inner mental and physiological states. Despite profound knocks from many research fields over the years, behaviourism still attracts some philosophers and psychologists.

"Our metaphorical thought is rooted in our bodies – a form of cognition that is nothing if not deep"

One of the biggest challenges to Chater may yet come from AI, the very thing he thinks is unlikely to come close to replicating the human mind. "If imagination and metaphor is the secret of our intelligence," he says, "then that secret may, perhaps, be safely locked away in the human brain for centuries and perhaps forever" – certainly beyond the reach of AI.

The inventors of AlphaGo Zero at Google's AI outfit DeepMind may beg to differ. In 2017, in just three days, AlphaGo Zero taught itself the game of Go well enough to defeat the previous AI champion, AlphaGo, by a score of 100 to 0. There is nothing "flat" about AlphaGo Zero's machine-learning architecture. It is called deep learning for a reason. It is not human-style general intelligence, but rumblings are afoot that it is only a matter of time. ■

Anil Ananthaswamy is a consultant for *New Scientist*

Fake it, don't make it

Nothing is what it seems at a new show, finds **Simon Ings**

Fake, Science Gallery Dublin, Ireland, to 3 June 2018

HAD you $1800 to spend on footwear in 2012, you might have considered buying a pair of Rayfish sneakers. Delivery would have taken a while: after designing the patterned leather yourself, you then had to wait as the company grew a pair of transgenic stingrays in its Thai aquaculture facility to the age when the biocustomised skins could be harvested.

Alas, animal rights activists released the company's first batch of stingrays into the wild before harvesting could take place, and the company suspended trading. Scuba divers still regularly report sightings of fish sporting the unlikely colourations that were Rayfish's signature.

Rayfish was, you will be pleased to hear, created by three Dutch artists out to provoke debates around our relationship with biotech, animals and consumerism. Their work features in a show called Fake at Science Gallery Dublin in Ireland, which sells itself as the place "where art and science collide".

The word "collide" is well chosen. "We're not experts on any one topic here, and we're not here to heal any 'rift' between science and art," says Ian Brunswick, the gallery's head of programming. "When we develop a show, we start from a much simpler place, with an open call to artists, designers and scientists." The team asks them what they think of the idea they plan to explore, and if they have any pre-existing work that might fit. Scientists in particular often underestimate which elements of their work will captivate, says Brunswick.

Founded under the auspices of Trinity College Dublin, the Science Gallery is becoming a global brand thanks to the support of founding partner Google.org. London gets a gallery later this year; Bengaluru in India in 2019.

The aim isn't to educate, but to inspire visitors to educate themselves. Brunswick recalls how climate change, especially, triggered this shift in how public educators see their role: "I think many science shows have been operating a deficit model: they fill you up like an empty vessel, giving you enough facts so you agree with the scientists' approach. And it doesn't work."

A better approach, Brunswick argues, is to give the audience an immediate, visceral experience of a subject. For example, in 2014, the gallery called its climate change show Strange Weather, precisely to explore the fact that weather and climate change are different, and that weather is the only phenomenon we experience on a daily basis. It got people to ask how they knew what they knew about climate – and what knowledge they might be missing.

Playfulness characterises the current show. Fakery, it seems,

"Scientists in particular often underestimate which elements of their work will captivate"

is bad, necessary, inevitable, natural, dangerous, creative and delightful all at once. You can (and you should) visit the faux-food deli and sample a caramelised whey product – here from Norway and very odd – that everyone labels cheese because what else would you call it?

Then there is a genuine painting that became a fake when its unscrupulous owner changed the artist's signature. And the Chinese phones that are parodies you couldn't possibly mistake since they come in all sorts of forms, from Pikachu to cigarette packets. There is also a machine that will let you manipulate your fake laugh to sound genuine.

Directly above Rayfish's sneakers, on the upper floor of the gallery, I saw Barack Obama delivering fictional speeches. *Synthesizing Obama,* a work in progress by researchers from the University of Washington, is a form of lip-syncing in which audio files of Obama speaking are converted into realistic mouth shapes. These are blended with video images of Obama's head as he delivers a completely different speech. It is a topical piece, given today's accusatory politics, and a chilling one. ■

FREDDIE STEVENS

Rayfish sneakers created by Dutch artists interested in biotech issues

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Biomedical Engineering, University of Strathclyde, Glasgow G4 0NW
Telephone: **0141 548 3781** Email: **carol.b.mcinnes@strath.ac.uk**

EDITOR'S PICK

A blow to craft beer, a boost for ale pie

From Alastair Mouat, Biggar, South Lanarkshire, UK

You report on a genetically engineered yeast that makes a beer taste of hops without the need for hops (24 March, p 19). Is it possible that the cost of producing such a yeast would be as great as the cost of using hops? In any case, the greatest cost element in producing beer commercially is often the duty. The cost of materials usually pales into insignificance. If there is an economic advantage, then perhaps the big international brewers would be the ones to delight in any minuscule savings per litre and would also welcome the possibility of bringing even more consistency to their somewhat bland products.

This may, however, damage the craft brewers, who welcome variation and revel in the challenge of producing beers with a wide range of styles and flavours, using the huge number of hops varieties available from all over the world.

Finally, yeast is a very versatile organism and I'm sure that a little more genetic fiddling could produce a beer that tastes of pie, thus killing two birds with one stone in a quick lunch break.

So, when do we lose the wisdom babies have?

From Sarah Fisher, Greensboro, North Carolina, US

Anil Ananthaswamy, reporting work on babies' sense of morality, mentions that they preferentially pay attention to material that conflicts with their beliefs (17 March, p 15). In contrast, *New Scientist*'s opinion writers complain frequently about adults preferentially viewing material that supports their beliefs. Has anyone done any research on when this change takes place and how to prevent it?

On the value of antidepressants

From Robert Proctor, Ballarat, Victoria, Australia

Clare Wilson discusses the controversy over the effectiveness of antidepressants (3 March, p 27). As a psychiatrist with more than 40 years' experience, I am surprised the debate still rages.

In psychiatric and research communities, there is total agreement that antidepressants are an incredibly valuable intervention in the treatment of major depression. Not all are effective for all patients, and some are generally more effective than others. For major depression, it is generally agreed that a particular antidepressant will be effective in around 60 per cent of patients. The challenge with the 40 per cent is to select another one, preferably with a different mode of action, and hope it will be effective.

The case with mild or moderate depression is less clear. I doubt that many psychiatrists would prescribe antidepressants in mild depression: psychological therapy would be more appropriate. They

"Blame us now, just like 2008 was the fault of home owners... OK, now I'll read the article"

Fahad Raja hits back at the suggestion that "our" obsession with a "free" internet led to the Facebook data row (7 April, p 24)

may be effective in moderate depression. Often the response is better combining psychological support and medication.

Another take on the idea of a colour bar

From Rod Ward, Southsea, Hampshire, UK
Frank Swain's article on colour blindness was interesting (17 March, p 38). I also find Jasper Fforde's novel *Shades of Grey* fascinating. It describes a society segregated by levels of colour vision. He summarises it: "Visual colour has become commodified, the social pecking order and levels of authority are not based on intellect, cash, ability, or the best liar, but which colour you can see – Purples are at the top of the heap and Reds at the bottom, with the Greys who see no colour at all as the lowly drones."

Scientists, don't rush to puff out your chests

From Trevor Hussey, High Wycombe, Buckinghamshire, UK
It may be the case that any truths about the world that we find in the future are most likely to be found by science rather than philosophy, as Philip Ball says (3 March, p 46). But before scientists puff out their chests, they should reflect on the fact that the science that makes the discoveries may not fit their idea of what science is.

Scientific methods have evolved and diversified over time in ways that would amaze and puzzle the early pioneers. This has happened with the help of philosophers and philosophically minded scientists. Should scientists seek truth or understanding or better theories, or try to find ways of describing reality independently of human prejudices? Such questions will not be resolved without the help of philosophers succeeding David Hume and Thomas Hobbes.

The same topics still make for a good story

From Cherry Lewis, Bristol, UK
You ask whether all publicity for scientific findings is good, in the context of Cheddar Man (3 March, p 5). In June 1788, the celebrated surgeon John Hunter opened his (now) famous museum. In attendance were the literati of London and, of course, the press.

Of particular interest was Hunter's large collection of skulls, which he had arranged in what he believed to be "a regular and continued gradation... from the most imperfect of the animals, to the most perfect of the human species". Hunter deduced that our first parents, Adam and Eve, "were indisputably black". As you can imagine, the press had a field day.

Some 230 years later, the suggestion that Cheddar Man was black has had much the same effect. It seems our hunger for a good story never diminishes.

Equal pay and the gender pay gap are different

From Julie Richards, Basingstoke, Hampshire, UK
You discuss how the gender pay gap permeates science and engineering (3 March, p 5 and p 22). It is important to highlight and address pay disparity – and it is also important not to confuse equal pay and the gender pay gap.

Consider eight female and two male science employees, each earning £50,000, working for a director who earns £100,000. With a male director, the ›

average male pay is £67k and average female pay £50k. With a female as director, the average male salary is £50k and the female average £56K. In both cases there is no equal pay issue but there is a gender pay gap – in one instance actually in favour of the females – because it is a statistical analysis.

The gender pay gap has a much more complex personality and falling into the habit of equating the two is not helpful if we are to address real behaviours and attitudes to ensure better career progression for women within science and engineering – or for men in those professions where women dominate.

Perhaps humans could be de-domesticated

From Daniel Hackett, London, UK
Colin Barras's article on the domestication of humans highlights genetic similarities to domesticated animals and says these may have arisen because tameness helped human cooperation and hence boosted survival (24 February, p 28). But what happens if environmental conditions change so that "feral/caveman" characteristics are favoured once again?

After a pandemic, loners might be the survivors of contagion. And when resources wane, I fear cooperation may no longer be a good survival tactic. Throwbacks to every clan for themselves would be likely.

From Heather Brindley, Canberra, Australia
Human self-domestication made for a very interesting article. But perhaps the word "gracile" would be a better description of the relatively lighter build of domesticated species. The word "feminine" comes with a lot of human-specific cultural baggage.

From Peter Daymond-King, Helensville, New Zealand
I do not find the idea that our ancestors domesticated themselves very convincing. After all, wolves learned to cooperate in a pack without showing signs of self-domestication. I wonder whether our ancestors were domesticated by Neanderthals and that our predilection towards inventing gods "in our own image" is a memory of this.

If leashes are bad for dogs, fences are for cows

From Ray Reed, Basingstoke, Hampshire, UK
Danny Chambers advises the abolition of electric dog training collars (10 March, p 24). Should he not include electric stock fences?

Atomic clocks are in fact widely travelled

From Tony Randle, Horsham, West Sussex, UK
You say that an atomic clock has been used to take measurements outside a lab for the first time (17 February, p 17).

But in the 1971 Hafele-Keating experiment, several atomic clocks were used to test relativistic time differences, when flown on airliners and compared with a reference on the ground.

Other such experiments have been performed to verify both aspects of Einstein's time dilation predictions. GPS satellites have four on-board atomic clocks. These gain about 38 microseconds per day and this must be corrected otherwise the position calculated by the receiver will be out by a number of kilometres.

There was scepticism when the US GPS satellites were designed about the need for this relativistic correction, so provision was made to turn it off. It never has been, and it remains the best everyday proof of Einstein's time concepts I can think of.

The editor writes:
■ The researchers clarify that theirs is the first optical atomic clock to do field measurements.

Concrete is a disaster in more ways than that

From Andrew Sanderson, Spennymoor, County Durham, UK
Julian Smith describes the ecological disasters generated by digging sand for use in concrete (17 February, p 35). These are only part of the story. Manufacture of cement causes around 5 per cent of carbon dioxide emissions.

TOM GAULD

For the record

■ **Scorchio! Temperatures on exoplanet K2-229 b reach 2033 kelvin, or 1760°C (31 March, p 16).**
■ **Tyler Hern joined the mussel team at the White Sulphur Springs National Fish Hatchery in West Virginia after it first raised purple cat's paw mussels (10 March, p 38).**
■ **The caves in northern Italy where Marco Peresani and colleagues found evidence of Neanderthals butchering bears are called Rio Secco and Fumane (31 March, p 10).**

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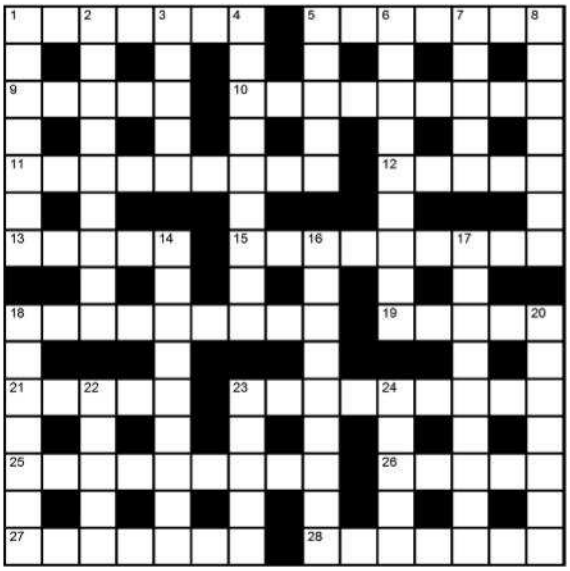
CROSSWORD

Compiled by Richard Smyth



Crossword No17

ACROSS

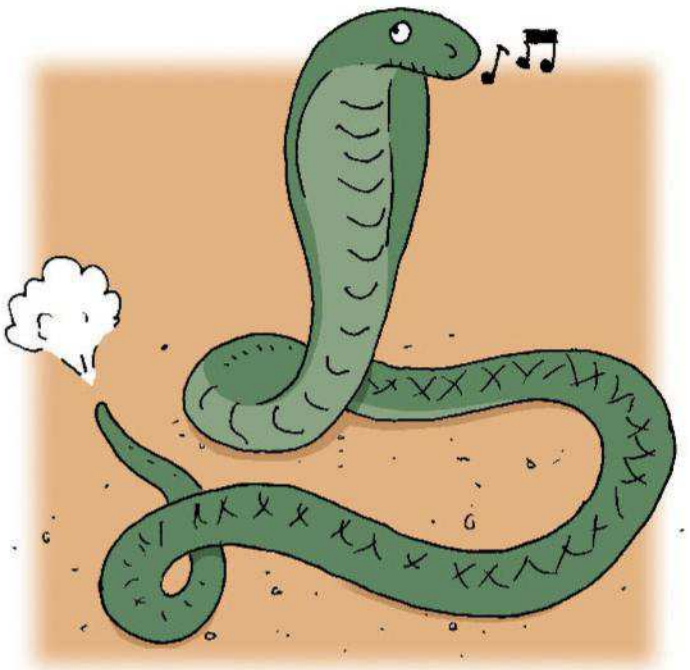
1 1961 sci-fi novel by Stanisław Lem (7)
5 Antennas for televisual broadcast (1,1,5)
9 Polish-designed brand of portable tape recorders (5)
10 Vessel for culturing cells (5,4)
11 Insecticide made from the chrysanthemum flower (9)
12 Prefix meaning "over" or "above"; the H in HTTP (5)
13 Gherman ___ (1935–2000), cosmonaut, second person to orbit Earth (5)
15 Female sex hormone (9)
18 Device that generates a tomogram (9)
19 Nassim N. ___ (b.1960), author of *The Black Swan* (2007) (5)
21 A planet's orbital periods (5)
23 Free-floating cell, such as a blood cell (9)
25 System diagram using graphic symbols (9)
26 The animal and plant life of a region (5)
27 Solid aggregations of cells that may form on muscles or vocal cords (7)
28 ≠ 0 (3-4)

DOWN

1 Temporary phenomenon of the sun's photosphere (7)
2 The inverse operation to exponentiation (9)
3 The US Air Force's rapid execution and combat targeting system for ICBM launches (5)
4 Explosive final stage of the life of a massive star (9)
5 Largest moon of Saturn (5)
6 ___ Group, engineering company founded in 1955 (9)
7 The Santa Cruz Institute for Particle Physics (5)
8 ___ myrtle, plant native to the North African desert (7)
14 Term for a base 20 numeral system (9)
16 Solid that may be made by splitting a bicone and rotating one of the halves by 90 degrees (9)
17 Monosaccharide sugar whose name is derived from the Latin for "milk" (9)
18 Protease formed in the small intestine (7)
20 Fertile cross between cattle and American bison (7)
22 Sap-sucking insect such as a greenfly (5)
23 1973 convention on endangered species (5)
24 ___ heat island, metropolitan region with temperatures higher than in the surrounding area (5)

Answers to crossword No16

ACROSS: **1** RELICT, **5** BUDAPEST, **9** PUDDLING, **10** DUPLEX, **11** PLEXIGLASS, **12** ROOT, **13** DRILL RIG, **16** NILGAI, **17** URANUS, **19** GOEPPERT, **21** TECH, **22** MASTECTOMY, **25** BRUNEL, **26** HYDROXYL, **27** WHIMBREL, **28** ROTARY. **DOWN:** **2** EQUAL, **3** INDEX, **4** TRIGGER, **5** BIG BANG, **6** DODGSON, **7** PAPERCLIP, **8** STEGOSAUR, **14** RARE EARTH, **15** LANTHANUM, **18** SAMPLER, **19** GASOHOL, **20** E-READER, **23** TROUT, **24** MAYER.



PAUL MCDEVITT

WHEN zoologist Dani Rabaiotti's teenage brother asked her whether snakes fart, she was stumped. So she asked on Twitter, and snake expert David Steen informed her that they do. Soon, the internet was abuzz with enquiries about animal flatulence, adorned with the hashtag #doesitfart? A year later, Rabaiotti has co-authored a book titled *Does It Fart?*, offering an definitive guide to animals' rear-end gas emissions, that went on sale in the US last week. Here are a few things it tells us.

Rabbits, we discover, can suffer from a gas build-up called intestinal stasis, which can quickly become fatal unless the gas is released. When startled, zebras begin to run and the motion propels gas from their body, causing them to fart loudly with each stride. An insect called the beaded lacewing farts on the termites it feeds on to stun and kill them. And while there are nearly 10,000 species of bird, none of them fart.

MORE air of mystery: scientists are scratching their heads over a video of a smoking elephant. The footage, recorded by Vinay Kumar of India's Wildlife Conservation Society, shows a female elephant in the Nagarhole forest blowing a cloud of ash from her mouth after picking up charcoal from the ground, presumably to eat. The area had recently been cleared by a controlled fire.

A taste for chargrilled vegetation hasn't been observed in elephants before, but it's not unheard of in the animal kingdom. Red colobus monkeys on the Tanzanian island of Zanzibar, for instance, are known to eat charcoal, probably to neutralise the toxins found in the mango and almond leaves they eat. Charcoal also helps to soothe digestive troubles – so perhaps this was one elephant with a jumbo upset stomach.

Our colleague received an ominous press alert from Penguin books for Jim Al-Khalili's new tome *Sunfall*, "due to be released 1st January 2098". What does he know that we don't?

"WHOEVER saves one life saves the world entire," according to the Talmud, but this isn't always true, as a man in the UK demonstrated rather graphically. After spying a heron swallow a newborn duckling, he shot the offending bird and cut it open to remove the duckling from its stomach. "But obviously he was then left with a dead heron," the North Wales Police rural crime team reported on Twitter.

All wild birds are protected in the UK, so killing one can result in a £5000 fine and six months in jail. However, as it was the man's first offence and he had confessed voluntarily, the police decided to let him off with a caution.

Despite the light ticking off, team leader Rob Taylor dismissed claims of a bias against herons, stating: "As a police team, we're extremely caring toward wildlife offences." The duckling lived to quack another day.

THE privatisation of space flight continues: amateur rocket man "Mad" Mike Hughes is feeling over the moon following a successful ascent to 570 metres in his home-made bottle rocket last month in Amboy, California.

His goal is to reach an altitude of 110 kilometres, a vantage point from which he will be able to authoritatively report on whether Earth is flat or not.

In 2014, the 61-year-old limo driver soared over Arizona in his steam-powered rocket. A planned launch late last year in California was scrubbed after the Bureau of Land Management denied him permission to fly over heritage sites. By modifying the launch ramp he had built from a mobile home, Hughes was able to avoid any infringements.

Although he has yet to flatten the "conspiracy" that has promoted a globist model of Earth for the past few millennia, Hughes is out to bust myths or die trying.

A COUNCILLOR in Washington DC has apologised for a video in which he claimed recent snowfall in the city was the result of a weather-control programme run by Jewish financiers.

On 16 March, Trayon White Sr shot a brief video on his mobile phone as he drove to work, telling viewers: "It just started snowing out of nowhere… Pay attention to this climate control… this climate manipulation… That's a model based off the Rothschilds controlling the climate to create natural disasters they can pay for to own the cities…"

The Rothschilds, a wealthy banking dynasty, have been the subject of numerous conspiracy theories over the centuries, accusing them of orchestrating world events. When *The Washington Post* asked for clarification, White initially replied: "The video says what it says."

But when the paper published its story, he recanted, stating: "I did not intend to be anti-Semitic, and I see I should not have said that after learning from my colleagues."

Feedback thinks there are quite enough climate change conspiracies to be found on Capitol Hill without this one joining the mix – if only the others would be retracted as swiftly.

YOU have been supplying Feedback with scientific theories forged by child minds. Charlie Robinson says, "I was very impressed with the lateral thinking of my 3-year-old son." Looking up at a half moon one night, he enquired, "Daddy, does someone have to go up there on a ladder to fold it?"

You can send stories to Feedback by email at feedback@newscientist.com. Please include your home address. This week's and past Feedbacks can be seen on our website.

I spy ewe

After I released a lamb that had got its head stuck in a fence, it ran halfway across the field to a ewe and immediately started suckling. I heard no calling, so how did the lamb recognise its mother from all the other ewes it ran past? It can hardly have been the coat she was wearing.

■ To a farmer, the lamb's behaviour is normal. Many animals recognise their young or mothers by sight, sound or smell, and sheep are no exception.

In the first few hours after a lamb's birth, it is crucial that the ewe and lamb aren't disturbed so they are able to bond. They will then recognise each other among hundreds of other ewes and lambs, and over distances of hundreds of metres. If they become separated, the first method they use to find each other will often be calling. When sheep are put in an enclosure for husbandry purposes, it is important to return them to their paddock with sufficient daylight hours for the ewes and lambs to "mother up". If there are a lot of them, there will be a symphony of bleating until they all find each other.

Sheep are great at recognising, differentiating and remembering sheep and even human faces. Our daughter raised an orphaned lamb in 2003. Even though she only returns home once a year and he lives in a paddock with other sheep, he still remembers her and always seeks her out for a pat and special treats.

Sheep aren't credited with a high level of mental capacity and are often thought of as being stupid. But having observed ovine behaviour for many years, I could write a book espousing their high mental capacity, great memory and interesting habits.
Anna Butcher
Brookton, Western Australia

■ The lamb didn't recognise its mother by sight, but by smell. Humans tend to pay more attention to sight when finding things. Most of us have no idea what it would be like to experience life through a greater reliance on other senses, although people who are blind, for example, can become more attuned to input from their other senses, such as hearing.

Dogs have an excellent sense of smell and they aren't the only ones. Many animals, including sheep, rely on other senses, including hearing and touch, but smell tops the list.
Courtney Schumacher
via email, no address supplied

■ When lambs are newly born, ewes usually keep them close. But lambs grow up fast. Within a few days, the ewes encourage them to become more independent by allowing them to move further away. Yet when ewes with new lambs are disturbed, they usually immediately know where their lambs are. In the case of the lamb stuck in the fence, the ewe may well have known exactly where it was, and was happy to take a break from the demands of motherhood for a while.

Any person working with the same group of sheep will soon be able to identify them by their looks, the way they walk, their behaviour and their bleat. The sheep probably do this too.
Jan Horton
West Launceston, Tasmania, Australia

A degree of uncertainty

Life on Earth depends on liquid water and the temperature at which it freezes or boils. How much would the values of 0°C and 100°C need to change to make life here unsustainable, or hugely different?

■ Due to its strong hydrogen bonding, water has a high freezing and boiling point for its molecular weight of 18. In comparison, ethane, with a molecular weight of 30, freezes at -182.8°C and boils at -88.5°C. If water had the same level of hydrogen bonding as ethane, it would freeze and boil at much lower temperatures, and Earth as we know it would be dry.

Organisms seem to require a liquid solvent for transporting materials, so Earth might be lifeless if water boiled at around 40°C. This is because water vapour is a greenhouse gas. Once runaway evaporation of the oceans began, the temperature would rise, causing ever more evaporation.

Similarly, if water turned to ice at say 30°C, all the planet's oceans would freeze right down to the sea floor. In this scenario, runaway cooling from reflective white ice wouldn't be counteracted by any amount of carbon dioxide emissions, leading to a permanent "snowball Earth".

However, one could argue that life maintains its own conditions for survival. The limits for life as we know it are then how much heat or cold organisms can tolerate. We have thermophilic organisms that can live above 120°C, while psychrophilic bacteria can live at -20°C. So life could probably exist in some form even if water boiled at 0°C or froze at 100°C.
Hillary Shaw
Newport, Shropshire, UK

This week's question

BRIGHT SPARK?
Some restaurants celebrate customers' special occasions by planting burning sparklers onto food, showering it with sparks. Sparklers typically contain an oxidising agent such as potassium nitrate, which yields nitrite as a combustion product. The European Food Safety Authority specifies a safety limit for nitrite ingestion of 3.7 milligrams per day per kilogram of body weight. How much nitrite would someone ingest by eating a slice of sparkler-enhanced birthday cake?
John Gordon
Datchworth, Hertfordshire, UK

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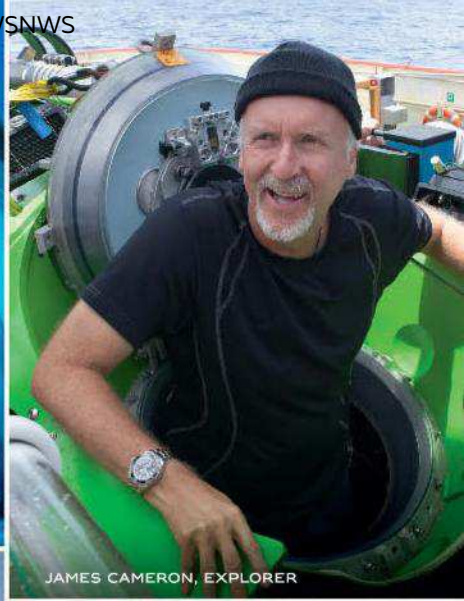
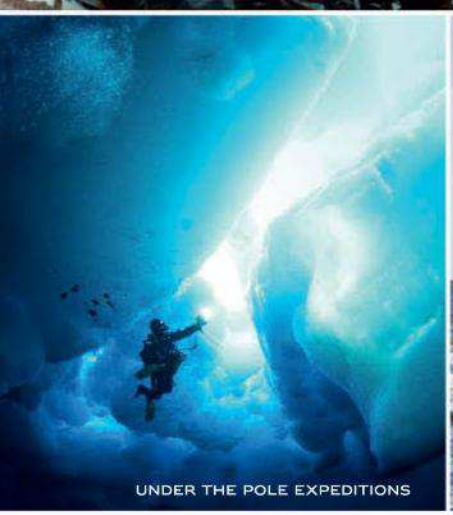
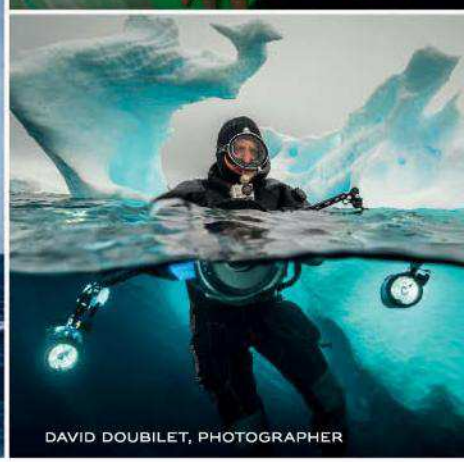
SIR EDMUND HILLARY AND TENZING NORGAY, EVEREST, 1953


SYLVIA EARLE, OCEANOGRAPHER


JAMES CAMERON, EXPLORER


UNDER THE POLE EXPEDITIONS


TRIESTE, 1960


DAVID DOUBILET, PHOTOGRAPHER

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