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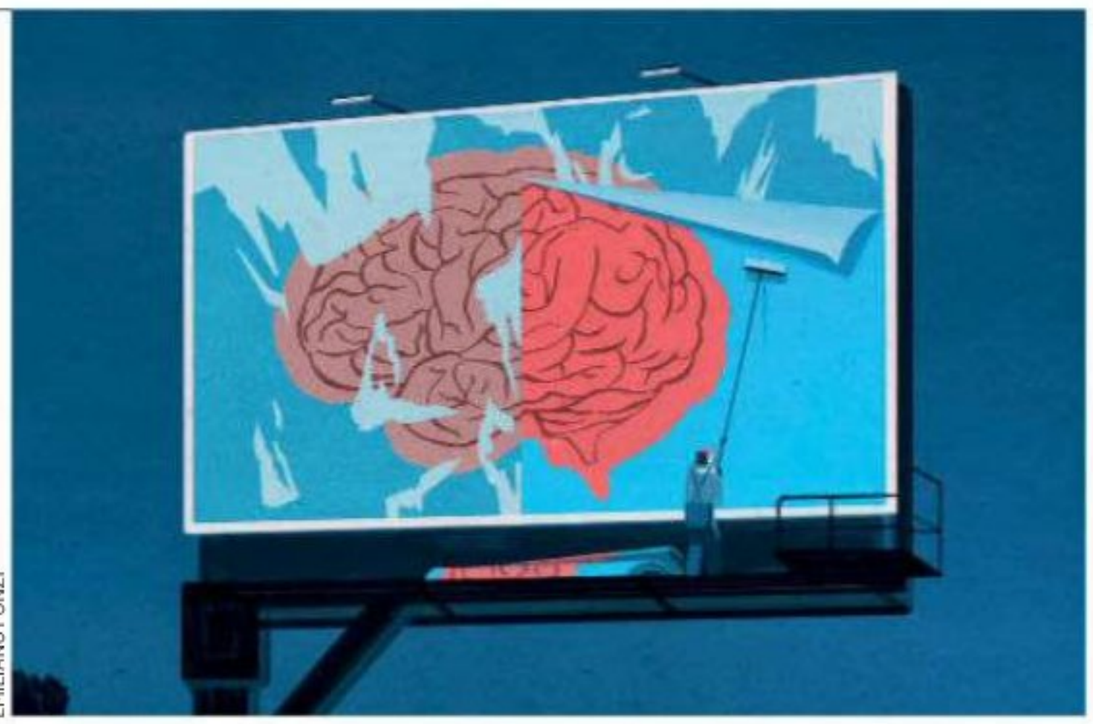

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REUTERS/STEPHANIE KEITH

Protest? Yes, we can

We mustn't let a superpower turn its back on rationality

THE stamp of jackboots, raps on the door, marches and uniforms; these are what we associate with the emergence of an authoritarian state. The reality is less dramatic: life for most people may carry on much as usual – except they will no longer have any sway over the governing of their nation.

Authoritarianism is on the rise, from Turkey to the Philippines – and now the US. The Republicans, led by Donald Trump, are rapidly dismantling any forces that might hold them accountable. Ethical concerns and conflicts of interest are being brushed aside. Trump's obfuscatory style and "fake news" has confounded the press. New voter registration laws are likely to weaken political opposition.

And empiricism is being stripped out of government, with scientists finding themselves on the front line. Climate researchers are squaring up to the potential destruction of their careers and life's work (see page 23), while those in other fields wait to see if they will be deemed "politicised". New laws mean that Congress can choose to ignore inconvenient truths at will (14 January, p 25).

All this should deeply concern anyone who values democracy and good governance, whatever they think of the Trump team's project to reshape political, social and fiscal norms. For those who actively oppose it, life is likely to get tough – particularly if the US turns its formidable surveillance capability on domestic dissenters.

Will that happen? The UK has the dubious distinction of leading the world in legalised snooping. Its ruling Conservative party is indulging its own authoritarian tendencies, although Prime Minister Theresa May doesn't praise autocrats as Trump does.

Still, the UK's track record does not inspire confidence. The precursor to May's Investigatory Powers Act, held up as an anti-terrorism measure, was used by local councils to monitor dog fouling, and by police forces to reveal the sources of journalists who had embarrassed them.

"An authoritarian US government will jeopardise not only its own citizens but all of humanity"

Now May's "snoopers charter" – technically vapid, over-broad and open to abuse – has been slapped down by the European Court of Justice, which said it would cause people "to feel that their private lives are the subject of constant surveillance". We know that such feelings alone cause people to act differently. That is not freedom.

But with Brexit looming, the IP Act may come into effect anyway, barring pitched resistance from netizens. And the US is set to follow the UK's lead: while on the campaign trail, Trump enthused about domestic surveillance (see page 22). Few seem to appreciate the depth of social control that's now possible – especially if the digital titans who hoard our data can be persuaded or coerced into giving it up. Worryingly, only a few have publicly said they won't.

Such control would make it far harder to mobilise opposition to measures such as US withdrawal from the Paris climate accord, or presidential endorsement of anti-vaccination myths. The ruling party could freely put the US into reverse in areas ranging from contraception to nuclear weapons proliferation (see page 24), despite their slender mandate.

The stakes are high. The world, not just the US, faces threats that range from global warming to antibiotic failure to pandemics. A US government that holds science in such low regard will be poorly equipped to deal with these. And if it stifles its citizens' ability to protest its denialism and ignorance, the US will jeopardise not only its own people, but all of humanity. So protest we must – for all our sakes. ■

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Junk is mounting up

E-waste spikes in Asia

THE spreading tech boom comes with an increasingly global cost. From 2010 to 2015, the volume of electronic waste generated in East and South-East Asia rose 63 per cent, according to a report from the United Nations University.

Electrical or electronic devices are not always properly recycled or disposed of. Instead, such e-waste is often burned or washed in acid to extract the valuable metals inside. This can pollute water and air, and lead to cancers and fertility problems in workers exposed to the fumes.

Researchers studied e-waste generation over five years in 12 Asian countries including China, which saw the amount of e-waste it produced more than double. Reasons for the rise include an increase in products for sale and a growing middle class that can afford to buy them, they say.

"More and more gadgets and toys are coming with either a plug or a battery and it's all substantially contributing to an increase in e-waste," says lead author Ruediger Kuehr.

The rise is big but not unexpected for nations seeing rapid economic growth, says Jason Linnell, who leads US non-profit body the National Center for Electronics Recycling.

Although Asia generates the highest volume of e-waste as a continent, Europe and the Americas generate about four times as much per capita – and much of this waste is exported to poorer countries that lack the infrastructure to safely recycle it.

Obamacare repeal

REPEAL of Obamacare began in earnest last week, before Barack Obama had even left the White House (see page 22).

Both chambers of the US Congress have voted through a measure that will begin the process of dismantling Obama's Affordable Care Act (ACA), allowing major budgetary elements to be removed without cooperation from Democrats.

"We need more detail on how such a big task is to be accomplished, and how it will be any different"

Donald Trump has declared that his replacement plan for the ACA is almost complete, and will aim to offer health insurance for everybody. People covered under his new law "can expect to have great healthcare" in a simplified, less expensive form, he told *The Washington Post* on 14 January.

Trump claimed that savings will be made by forcing pharmaceutical companies to sell drugs more cheaply to the state-run health insurance systems Medicaid and Medicare.

Health experts say that, until Trump discloses more specifics, it's hard to know whether his plans would work. "We need more detail on how such a big task is to be accomplished, how it would be different from the ACA, and how it would pay for itself," says Nadereh Pourat at the University of California, Los Angeles.

It also remains unclear how the proposals will fit with an alternative plan that is due to be discussed later this month by Republican Party lawmakers.

Oryx de-extinct

THEY'RE back. Scimitar-horned oryx have been reintroduced to the wild after a two-decade absence, and are flourishing in their old stamping grounds.

The desert antelopes were once widespread across northern Africa, but were hunted to extinction in their natural habitat in the 1990s. Since then, the species has been kept alive in captivity in the United Arab Emirates, the US, Europe and Australia. Several hundred have also been reintroduced to fenced areas in northern Africa.

To test if the oryx could survive in the wild again, 23 were released into a remote part of Chad last August. They are doing well and one calf has been born, so another 23 will be released this week.

The animals have been fitted with GPS collars to monitor their movements. "So far, the animals look exceptionally healthy," says Jared Stabach at the Smithsonian's National Zoo and Conservation Biology Institute in Washington DC, who is involved in the project. "They seem to be adapting to the environment really well."

SPACE X

We have lift-off

Back in business

SPACEX successfully launched a Falcon 9 rocket on 14 January, its first launch since the explosion of one of its rocket four months ago.

The rocket took off from the Vandenberg Air Force Base in California and carried 10 satellites for US telecoms firm Iridium Communications. The satellites are the first of 81 set to be deployed in low Earth orbit.

The launch went smoothly, with the first stage of the rocket

separating from the second stage and landing back on a drone ship in the Pacific Ocean about 8 minutes after launch. All of the satellites were successfully deployed about an hour later.

For SpaceX, it marks a return from a major setback. In September 2016, a Falcon 9 blew up on the launchpad during a test. The explosion destroyed the rocket and its payload – an Israeli communications satellite that Facebook was planning to use to bring internet to underserved regions. SpaceX concluded that the explosion was due to a fault in a helium tank.

Sea ice record low

IT'S a new low point. The area of the world's oceans covered by floating sea ice is the smallest recorded since satellite monitoring began in the 1970s, according to the latest observations from the US National Snow & Ice Data Center in Boulder, Colorado.

That means it is also probably the lowest global sea ice has been for thousands of years.

In the Arctic, the low sea ice coverage is a result of both global warming and unusual weather events probably influenced by global warming. It has been so warm in the area, that on occasions this winter the sea ice has temporarily shrunk, instead of growing as it usually does.

But in the Antarctic, the current

"This is probably the lowest that global sea ice has been for thousands of years"

low in seasonal sea ice could just be a result of natural variability. In the long term, the extent of seasonal sea ice around the Antarctic is expected to decline as global warming continues.

Incurable infection

BACTERIA that resist nearly all antibiotics are continuing to spread worldwide. The US Centers for Disease Control and Prevention (CDC) has reported that a woman who died in Nevada last August was infected with *Klebsiella* bacteria that were resistant to 26 antibiotics – everything her hospital could throw at it.

We don't know how many totally antibiotic-resistant infections there are now, says Mike Sharland at St George's, University of London. According to the CDC, at least 90 per cent of multi-resistant infections in the US can still be killed by at least one antibiotic of last resort.

The woman probably caught the bacteria when she was hospitalised for a broken leg in India, where antibiotics misuse has led to soaring resistance, and some totally resistant bacteria.

Her infection might have been cured by one drug that is licensed for uses like this in Europe, but not in the US. Fosfomycin is an old drug that was replaced in the 1980s by more modern cephalosporin antibiotics. Researchers are now trying to resurrect and relicense such drugs for use in the increasing number of cases where newer ones fail.

Many primate extinctions ahead

THE majority of the world's primates are in deep trouble. There are as few as 20 or 30 Hainan gibbons left in China, and the trapdoor of extinction is gaping for the Javan slow loris. Even numbers of Madagascar's iconic ring-tailed lemur have slumped to around 2000.

These could be the next primates to disappear from our planet. But overall, the picture is even bleaker, with 60 per cent of all primate species globally predicted to vanish within between 25 and 50 years.

That's the gloomy conclusion from the largest ever review of the survival prospects of the world's 504 known species of non-human primate, 85 of them discovered since 2000. "This paper is a synthesis of the factors, at all scales, that are causing declines and extinctions," says Anthony Rylands of Conservation International, joint lead author of the report (*Science Advances*, e1600946).

The biggest harbinger of doom is clearance of forests for agriculture, both by local farmers and by big agro-industrial producers of commodities such as palm oil and rubber. Between 1990 and 2010, for example, agricultural expansion into primate habitats was estimated at 1.5 million square kilometres, an area three times that of France.

"Our paper is a plea to address the consequences of destruction and degradation of primate habitats worldwide," says Rylands.

CONSERVATION INTERNATIONAL/RUSSELL A. MITTERMEIER

Could be gone in 25 years?

60 SECONDS

Funding findings

Drug trials are more likely to have positive results if the researchers involved are financially linked to the pharmaceutical industry, finds an analysis of 195 studies. (*BMJ*, DOI: 10.1136/bmj.i6770). One explanation may be that negative results are in some cases less likely to be published.

Waves on Venus

A giant atmospheric phenomenon called a gravity wave has been spotted above Venus by the Japanese probe Akatsuki. Stretching some 10,000 kilometres, it may have been formed by winds travelling upwards after hitting mountaintops. The finding suggests surface winds on Venus are more varied than we thought (*Nature Geoscience*, doi.org/bxcp).

Seadragon showreel

Live ruby seadragons have been filmed for the first time in the wild in waters off Western Australia. These spiny fish were only identified as a species in 2015, based on DNA sequencing of four dried-out specimens. The footage shows the fish living among sponges 55 metres down, deeper than related species.

Biased beats

Prejudice may be a matter of the heart. Monitoring 32 people during racial bias tests found that they were more likely to make errors linked to bias when shown a photo of a black man during a heartbeat than in the gap between beats (*Nature Communications*, DOI: 10.1038/ncomms13854). This suggests some racial biases may be influenced by signals the heart sends to the brain.

Epic search halted

The search for the missing MH370 flight has been called off after three years. A few pieces of debris were found, but a sweep of about 120,000 square kilometres of the Indian Ocean yielded no clues to the plane's whereabouts.

AI takes on top poker players

Mastering the game could help AI with real-world tasks, finds **Timothy Revell**

A NEW game has been added to the grudge match between humans and artificial intelligence. AI has already mastered chess and Go, but in poker everything is still to play for.

"We're so good at poker that not even a supercomputer can beat us," says professional player Jason Les. "If we lose, we will also lose that prestige."

That could change this month. Les is one of four top players representing humans in the 2017 Brains vs AI poker tournament at Rivers Casino in Pittsburgh. They are each taking on a program called Libratus at Heads-Up No-Limit Texas Hold 'Em, which comprises one-on-one games with no limit on the size of bets. The 20-day contest involves 120,000 hands.

Although bots are common on online poker sites, an AI that can truly master the game is a tough challenge. Ahead of the event, the odds were on the reigning human champions, who won the last competition against the AI in 2015. "International betting sites are considering the AI to be a 4:1 or 5:1 underdog," says Tuomas Sandholm, one of the Carnegie Mellon University researchers who created Libratus. As *New Scientist* went to press, however, the AI was up by over $50,000 after almost 28,000 hands.

The AI has honed its strategies over the equivalent of 15 million hours of computation. Sandholm and his colleagues won't reveal exactly how it works, but they say it hasn't been fed a particular strategy and must, instead, learn the best approach for itself.

An AI that can beat poker professionals wouldn't just claim another gaming victory over humans. It would also signal an ability to work with imperfect information – a skill with a wide range of uses outside poker.

TIM KAULEN/CARNEGIE MELLON UNIVERSITY

Battling for humans

"Unlike chess or Go, you never have a perfect view of the state of play, which is much more like reality"

Poker is a difficult game for AI to conquer as players can only see the cards they hold and those on the table, but not their opponents' (see "Artificial intuition", below).

"Unlike chess or Go, you never have a perfect view of the state of play, which is much more like reality," says Michael Bowling, head of the Computer Poker Research Group at the University of Alberta, Canada.

Bowling is part of a team that created an AI called DeepStack that they say can consistently beat professionals at the one-on-one Heads-Up No-Limit form of the game – although the work is yet to be peer-reviewed. DeepStack uses machine learning and some strategic simplifications to assess the best real-time move to make. The researchers say DeepStack came out on top after playing 44,000 hands against 33 pros.

Previously, Bowling and his colleagues created a program to "solve" Heads-Up Limit poker, but Heads-Up No-Limit is a tougher test as betting is unrestricted. The number of possibilities in a game of Heads-Up Limit is around 10^{14}, but in No-Limit it's more like 10^{160}.

The heads-up variants are best suited to AI competitions. "If there were more players, the humans would simply gang up against the AI, shifting the odds by a huge amount," says Bowling. "No matter how sophisticated your AI was, it would still lose."

An AI that can excel at No-Limit poker could have applications in other tasks that require a strategy to be drawn up from limited information. This is the case in most real-world scenarios, such as when doctors must decide on people's treatment without knowing everything about them.

"It's inevitable that AI will eventually win," says Les. "That won't be the end of poker, but it will be a massive milestone for AI." ■

ARTIFICIAL INTUITION

AI has already conquered games of great complexity, from IBM's Deep Blue supercomputer beating Garry Kasparov in a chess match in 1997 to DeepMind's AlphaGo winning a tournament against top Go player Lee Sedol last year. So what makes poker such a challenge?

While Go is incredibly complex, both players can see all the pieces in play and use this to inform their moves. This is called a game of perfect information. In poker, however, players' cards are hidden from each other, so it is a game of imperfect information.

An AI could simply calculate the odds that its hand will win and play accordingly, but knowing how to bet is trickier. If the AI bet high every time it had a good hand, a human player would figure this out and exploit it. The AI therefore has to not only work out how to play, but also figure out its opponent - and balance computation with something akin to "intuition".

Shark deprived of her mate turns asexual

WHO needs males? A female shark has had babies on her own years after being separated from her long-term mate. It's a rare case of an animal switching from sexual to asexual reproduction.

Leonie the zebra shark (*Stegostoma fasciatum*) met her male partner at an aquarium in Townsville, Australia, in 1999. They had more than two dozen offspring before he was moved to another tank in 2012. From then on, Leonie had no male contact. Then in early 2016, she had three baby sharks.

Intrigued, Christine Dudgeon at the University of Queensland in Brisbane and her colleagues began fishing for answers. One possibility was that Leonie had been storing sperm. But tests showed that the young only had DNA from their mum, so were the result of an ability some sharks are known to have: reproducing asexually (*Scientific Reports*, doi.org/bw97).

"In species that are capable of both reproductive modes, there are quite a few observations of switches from asexual to sexual reproduction," says Russell Bonduriansky at the University of New South Wales in Sydney. "However, it's much less common to observe switches in the other direction."

In female sharks, an egg can be fertilised by an adjacent cell known as a polar body, Dudgeon says. This contains identical genetic material, leading to "extreme inbreeding", she says. "It's not a strategy for surviving many generations because it reduces genetic diversity and adaptability."

Yet, it may be necessary at times when males are scarce. "It might be a holding-on mechanism," Dudgeon says. "Mum's genes get passed down from female to female until there are males available to mate with." It's possible that the switch from sexual to asexual reproduction is not that unusual; we just haven't known to look for it, she says. Alice Klein ■

PLAINPICTURE/LUBITZ + DORNER

Eat less, live more?

Permanent diet extends primates' lives by years

PUT down the cake. Going on a permanent diet could make you live longer, if findings from monkeys hold true for people.

A long-running trial in macaques has found that calorie restriction makes them live about three years longer than normal, which would translate to about nine years in people.

Such a strict diet might not be for everyone, but understanding the mechanisms behind any benefits of calorie restriction may one day lead to anti-ageing medicines, says Julie Mattison at the National Institute on Aging (NIA) in Baltimore, Maryland. "The goal is to improve human health," she says.

Many studies have shown that calorie restriction extends lifespan for lab organisms, from yeast through to worms, flies and mice. This has prompted a few thousand people to choose to restrict their calories to between 1500 to 1800 kcal a day (women and men are usually advised to consume 2000 and 2500 kcal, respectively). Their hope is it will give them longer and healthier lives, and there's some evidence that such people have better blood cholesterol and glucose levels.

But it's unclear if the approach can really lengthen the lives of long-lived animals like us. Two trials of calorie restriction in macaques, which live around 26 years in captivity, have until now produced conflicting results.

The trials were set up in the late 1980s, and not all the monkeys

"Understanding calorie restriction could lead to anti-ageing medicines and improve human health"

have died yet. But an interim report from one group, based at the University of Wisconsin, previously found that the monkeys on a restricted diet were indeed living longer than the control group. However, the second study, run by the NIA, found there was no difference in the survival rates of their animals, which cast doubt on the entire premise.

Now the teams have compared their most recent results – and they have concluded that the trial with positive findings is the one to trust, because of problems with the NIA study (*Nature Communications*, DOI: 10.1038/ncomms14063). These include issues with the control group eating fewer calories than expected, and some of the animals beginning their restricted diet as juveniles – which reduces lifespan.

Even so, in the NIA trial, four of the monkeys that began the diet as adults lived to be over 40, breaking all known records for macaques – an observation which may cheer those who practise calorie restriction. However, picking out single results like this from a larger study isn't good evidence, says Mattison.

In the Wisconsin trial, animals did live significantly longer than controls – calorie-restricted males lived about two years longer, while calorie-restricted females lived about six years longer. There were also lower rates of heart disease and cancer in these monkeys. These are the major causes of death in people, lending support to the idea that the results apply to humans, says Luigi Fontana of the University of Brescia in Italy.

However, Brian Delaney, who is president of the Calorie Restriction Society, an organisation that supports the practice in people, says some who follow this diet are disappointed by the relatively modest benefits in monkeys compared with mice, which have lived up to 50 per cent longer than normal.

"Is it worth it?" asks Delaney. "My choice is to do it. But I'm so used to the diet that it really isn't very difficult for me anymore."

Delaney has been practising calorie restriction for 24 years. Until someone is used to it, the diet involves planning every meal with precision, and side effects can include feeling cold and reduced libido. **Clare Wilson** ■

Control bacterial genes with the flick of a switch

WE DON'T usually welcome bugs in digital technology, but that's about to change. Researchers have developed a way to control bacterial genes at the flick of a switch using electricity.

Synthetic biologists are eager to find ways to connect engineered organisms to electronics, so we can make living components for devices. The ability of custom-made microbes to sense the environment and make biological molecules would be particularly valuable for devices that work inside the body, says William Bentley at the University of Maryland.

"If you want to discover what's going on in the gastrointestinal tract or the oral cavity, if you can connect to electronics you have a way of interpreting what's going on and you may be able to manipulate it," he says. For example, a device could use an organism to sense chemicals produced by harmful bacteria in the body and secrete an antibiotic when it detects them.

To get specific genes in bacteria to respond to electrical stimulation, Bentley's team took advantage of what are called redox molecules. These biological molecules are found in all cells and can pick up and pass on electrons. They are said to have a reduced state when they gain electrons, and an oxidised state when they lose electrons.

The team also made use of naturally occurring genetic components in *E. coli* that respond to oxidative stress, which occurs when too many molecules in the cell are oxidised, making them dangerously reactive.

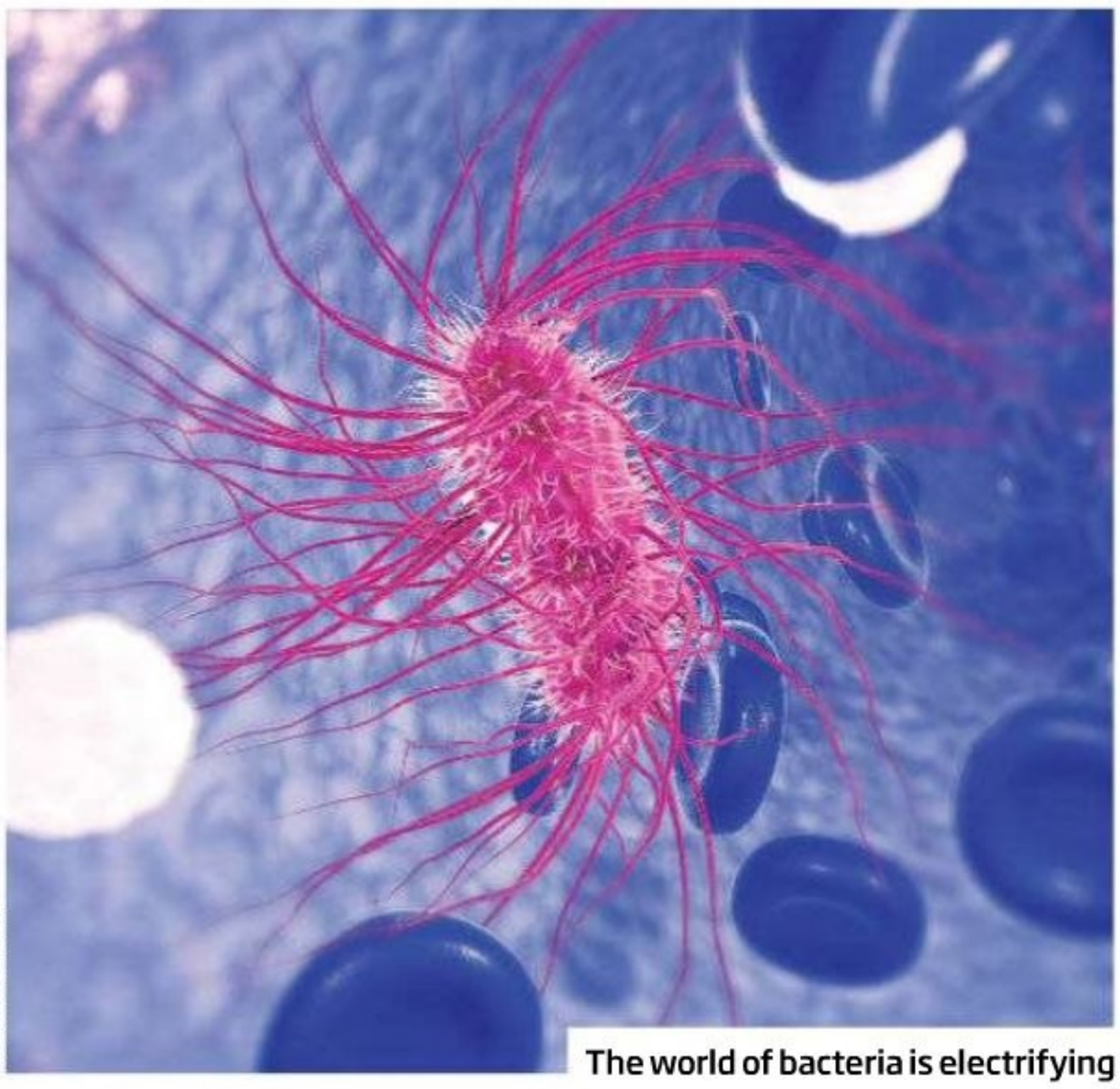
To apply electrical input, the researchers submerged an electrode in a liquid containing the bacteria. When the electrode supplies a positive charge, certain redox molecules get oxidised and trigger the genetic mechanisms that respond to oxidative stress. The bacteria can be engineered so that these mechanisms switch on any genes researchers want to target. When the electrode is negatively charged, the molecules get reduced and the genes switch off again. Using this principle, Bentley's team showed they can use electrical inputs to make *E. coli* swim or fluoresce on demand.

They also made the bacteria release a signalling molecule that caused other bacteria to fluoresce, showing that they can engineer one set of bacteria to respond to electrical charge by altering the behaviour of another set (*Nature Communications*, DOI: 10.1038/ncomms14030).

The procedure involves relatively little genetic "rewiring" of the bacteria, says Bentley. "We like to think about how you can minimally alter cells, but alter what they do in a controlled way."

One application could be in biosensors using engineered bacteria that detect certain chemicals. For example, bacteria could be programmed to identify a particular infection and respond by fluorescing. Richard Kitney, a synthetic biologist at Imperial College London, thinks uses like this could be developed quite quickly. "To get it working in the lab, you might be talking about a year or two," he says.

Further down the line, Bentley imagines programmed bacteria being used in ingestible pills that collect chemical data and produce drugs inside the body. **Sam Wong** ■



KATERYNA KON/SPL

The world of bacteria is electrifying

Dwarf galaxy merger is doubly pleasing

COLLISION imminent. Astronomers have found the first evidence of a dwarf galaxy smash-up about to happen – a finding that lends weight to two cosmological theories.

Pairs of large and medium-sized galaxies have been seen colliding and merging before. It's a different story with dwarf galaxies: they often hang out at the fringes of larger galaxies, whose gravity strips them of their stars before a merger can take place.

Now Sabrina Stierwalt at the National Radio Astronomy Observatory in Charlottesville, Virginia, and her colleagues have combed the Sloan Digital Sky Survey and found seven isolated clusters containing nothing but dwarf galaxies. Each group is compact enough that at least one pair in each is ultimately likely to merge (arxiv.org/abs/1701.01731).

Elena D'Onghia at the University of Wisconsin, Madison, had predicted in 2009 that unless gravity is doing something very strange, we should see clusters of dwarf galaxies all on their own, even near our galaxy.

"Based on dark matter theory, we expect a lot of little dwarf galaxies and clumps of dark matter in and around the Milky Way," she says. So why have these clusters been so hard to spot?

The answer lies in the idea that dwarf galaxies merge to form bigger galaxies like the Milky Way. If so, then few would survive nearby. Looking into the distant, early universe, we would expect dwarf galaxies to be numerous but also too faint to see.

"Dwarf galaxies live inside dark matter haloes, without which they wouldn't hold together"

Seeing these seven clusters fairly nearby suggests our theories of how galaxies form via collisions are right. It also suggests invisible dark matter is distributed much as we thought – in small patches throughout the universe, says Mike Boylan-Kolchin at the University of Texas, Austin.

Without the gravity of dark matter, dwarf galaxies wouldn't be able to hold together. "These galaxies are living in dark matter haloes," says Boylan-Kolchin.

As technology improves, we can hope more of these faint systems will come into view. Chelsea Whyte ■

ANDRESR/GETTY

Old blood can make us age

Betrayed by your own blood

Jessica Hamzelou

OLD blood may damage organs and contribute to ageing. Now a compound has been developed that seems to protect against this, preventing mouse brains from ageing.

The effects of blood on ageing were first discovered in experiments that stitched young and old mice together so that they shared circulating blood. Older mice seem to benefit from such an arrangement, developing healthier organs and becoming protected from age-related disease. But the younger mice age prematurely.

Such experiments suggest that, while young blood can be restorative, there is something in old blood that is actively harmful. Now Hanadie Yousef at Stanford University in California seems to have identified a protein that is causing some of the damage, and has developed a way to block it.

Yousef has found that the amount of a protein called VCAM1 in the blood increases with age. In people over the age of 65, the levels of this protein are 30 per cent higher than they are in under-25s.

To test the effect of VCAM1, Yousef injected young mice with blood plasma taken from older mice. Sure enough, they showed signs of ageing: more inflammation in the brain, and fewer new brain cells being generated, which happens in a process called neurogenesis.

Blood plasma from old people had the same effect on mice. When Yousef injected plasma from people in their late 60s into the bodies of 3-month-old mice – about 20 years old in human terms – the mice's brains showed signs of ageing.

These effects were prevented when she injected a compound that blocks VCAM1. When the mice were given this antibody before or at the same time as old blood, they were protected from its harmful effects.

"When we age, we all have decreased cognitive function, decreased neurogenesis, and more inflammation in the brain," says Yousef, who presented her findings at the Society for Neuroscience annual meeting in San Diego in November last year. "If we can figure out the mechanisms and reverse them, then we could promote healthy ageing. That's what I truly believe will come out of this research eventually."

"It's a sound study and it has a lot of potential," says Jonathan Godbout at Ohio State University in Columbus. He would like to see more data, but is cautiously optimistic that the work could lead to a treatment that could protect ageing brains.

"Nobody wants blood transfusions. We want rejuvenating proteins to help people age healthily"

Some teams have begun giving plasma from young donors to older people, to see if it can improve health (see "Fetch the young blood", below). But for the best chances of success, we'll also need to neutralise the damaging effects of old blood, says Yousef.

Miles Herkenham at the National Institute of Mental Health in Bethesda, Maryland, is impressed with Yousef's findings. It's surprising that a single protein seems to have such a huge effect, he says, but the results need to be replicated. "I like the idea, but I wouldn't want to rush into human trials yet," he says.

A drug that protects people from the effects of old blood would be preferable to plasma injections, says Yousef. Should transfusions from young donors turn out to be effective, it would be difficult to scale this up as a treatment for all. Drugs that block harmful proteins in our own blood would be cheaper, safer and more accessible.

"At the end of the day, nobody wants blood transfusions," says Yousef. "We want rejuvenating proteins and antibodies to help people age in a healthy manner." She is patenting her compound, and hopes to develop a treatment to protect people from the effects of ageing.

It is particularly promising that Yousef's antibody protects mouse brains without needing to pass through the protective barrier that separates it from the body's bloodstream – a stumbling block for many drugs. ■

FETCH THE YOUNG BLOOD

DOES young blood have restorative powers? There's anecdotal evidence that people who get transfusions of blood from under-25s feel better than those who receive blood from older donors.

Parabiosis experiments, which stitch together young and old mice, suggest there could be something in this (see main story). Researchers at healthcare firm Alkahest in San Carlos, California, recently injected blood from human teenagers into old mice, and found it made them more active and improved their memories.

However, we don't yet know what it is about young blood that keeps animals youthful. That hasn't stopped people from starting trials to see if transfusions can treat age-related diseases. One company, Ambrosia in Monterey, California, is offering such transfusions to anyone over 35 – with an $8000 price tag.

How dwarf whales killed largest shark

Richard Gray

WITH a jaw up to 3 metres wide that had the power to crush a small car, megalodon had a formidable bite. But it seems the largest shark to ever live preferred to snack on amuse-bouche rather than more substantial prey – and that could have been its downfall.

The 16-metre-long *Carcharocles megalodon* prowled the world's oceans for around 14 million years before dying out about 2.6 million years ago. Analysis of the fossils of marine mammals that lived in the oceans around 7 million years ago have provided the most detailed insight yet into the kind of prey it targeted. Distinctive scrape marks and wounds left on bones by the shark's huge, serrated teeth suggest it preferred hunting now-extinct dwarf whales and seals.

"The disappearance of the last giant-toothed shark could have been triggered by the decline and fall of several dynasties of small to medium-sized baleen whales," says Alberto Collareta at the University of Pisa in Italy.

The researchers believe a cooling climate, which caused a fall in sea levels as water was locked up in the polar ice caps and glaciers, led to rapid changes in the coastal environments where smaller baleen whales lived. This caused numbers of these smaller whales to fall while the changes favoured larger open-ocean whales that were too large for megalodon.

ETHAN MILLER/GETTY IMAGES

Not too big to fail

The changing climate also brought seasonal food booms around the poles, which helped drive the evolution of larger whales – like the giant humpback and blue whales of today – capable of making the long-distance migrations needed to feed there. It is possible that megalodon, more used to a warmer coastal habitat, was unable to follow them.

Collareta and colleagues have examined wounds left on fossils found in the Pisco fossil beds in Aguada de Lomas, Peru. Among those carrying marks left by megalodon teeth were the jawbone of a diminutive, extinct species of baleen whale called *Piscobalaena nana* and an early type of seal called *Piscophoca pacifica*. Both animals grew to less than 5 metres in length – under a third the size of megalodon (*Palaeogeography, Palaeoclimatology, Palaeoecology*, doi.org/bw8d).

But Dana Ehret, curator of palaeontology at the Alabama Museum of Natural History, believes megalodon may also have targeted larger whales from time to time. "I've seen a specimen from Virginia yet to be published of a fairly large baleen whale found with a megalodon tooth lying on top of an indentation in the bone," he says. It is unclear if the whale was alive or dead when the shark bit into it. "It could have been scavenging on the whales like modern white sharks do today," Ehret says.

Some modern sharks, however, have been seen actively targeting giant whales like humpbacks.

Catalina Pimiento Hernandez, a palaeontologist at the University of Zurich, Switzerland, says megalodon dietary preferences may have changed during their lifetime and depended on the area they inhabited. "More work is needed to be sure that megalodon globally preferred small prey rather than big," she says. ■

Squeezed light cools object to record low

IT'S the coolest object of all time. The temperature of a tiny round membrane, only 20 micrometres wide and 100 nanometres thick, has been lowered so that it is 10,000 times colder than the vacuum of space.

The usual way to make something extraordinarily cold is laser cooling, in which highly organised light dampens its thermal vibrations by slowing the random motion of atoms. The more organised the light, the more effectively it can cool things.

A new technique developed by a team at the National Institute of Standards and Technology in Boulder, Colorado, uses "squeezed" light to get atoms colder than is possible with regular laser cooling.

Squeezed light is more organised in one particular orientation and less in others. It has previously been used in other contexts, but never for cooling. "This research combines several fields that have existed for quite some time, so it's kind of surprising that no one tried to do this experiment before," says Amir Safavi-Naeini at Stanford University in California, who was not involved in the research.

By shining squeezed light on a thin aluminium membrane resembling the head of a snare drum, John Teufel and his colleagues lowered its temperature to about 360 microkelvin, or just 360 millionths of a degree above absolute zero (*Nature*, doi.org/bw8t).

"It's much colder than any naturally occurring temperature anywhere in the universe," says Teufel.

Individual atoms, quantum gases and collections of atoms called Bose-Einstein condensates have been cooled even further than this, but the membrane is the first object to reach such low temperatures.

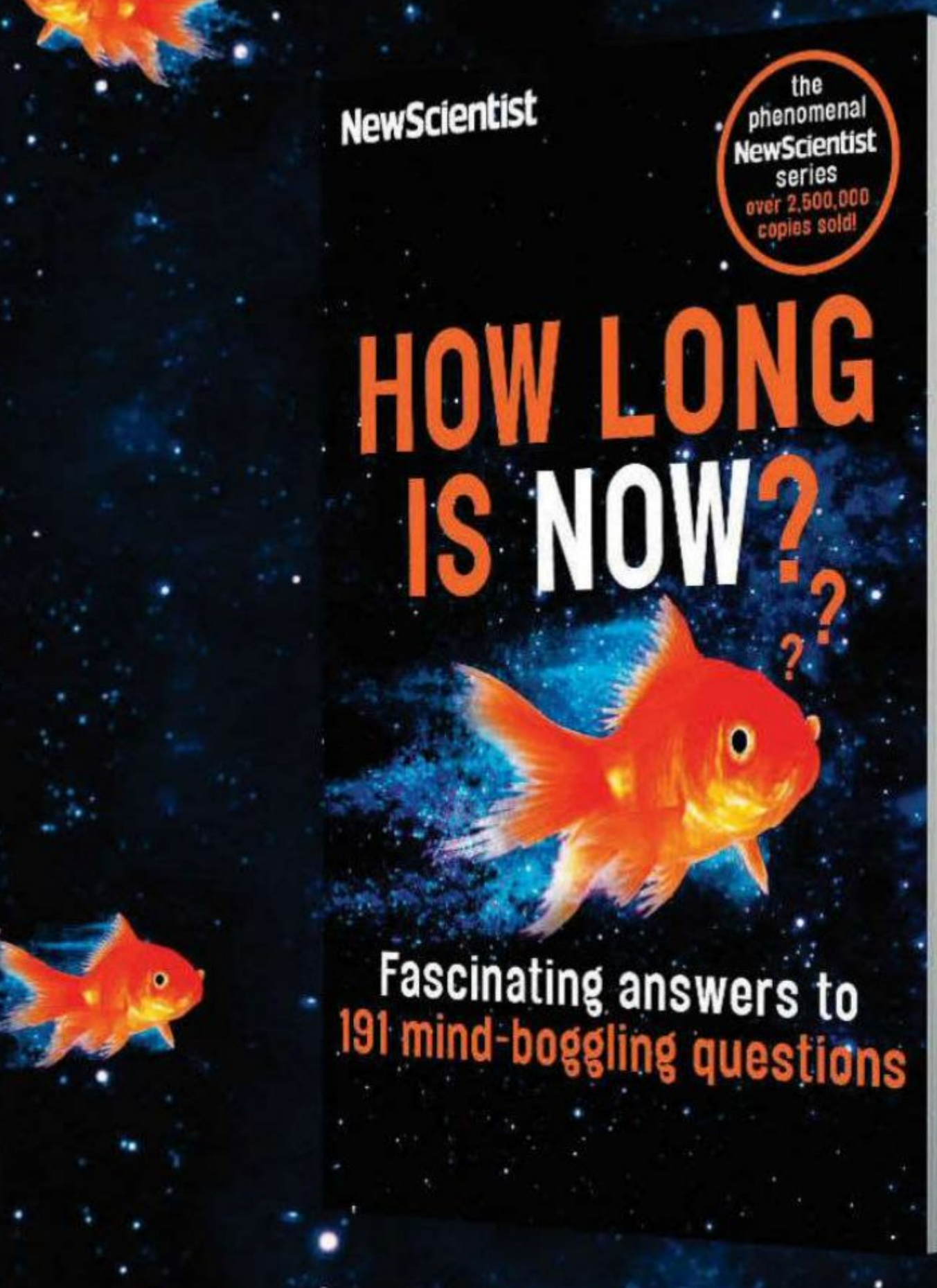
"The team lowered the tiny object's temperature so it was 10,000 times colder than the vacuum of space"

Supercooled systems like this could be used as extremely sensitive and precise sensors for measuring force or acceleration since they would register little random noise from their environment.

In the future, chilling qubits, or quantum bits, to this level in a quantum computer would help us probe the nature of the quantum world more effectively, says Teufel.

"Why don't we see these kind of quantum behaviours in our daily life, but we see them on an atomic scale?" he asks. "Where is the line in between?" He hopes supercooled systems like his team's might one day be able to show us. Leah Crane ■

WHY ARE DOGS' NOSES WET?



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Black cabs beat Uber on speed in taxi races

LONDON Bridge to Trafalgar Square. You take an Uber, I'll take a black cab. Ready, set, go!

A group of researchers led by Anastasios Noulas at Lancaster University, UK, raced taxi services on 29 journeys around London while developing a taxi price comparison app called OpenStreetCab. One researcher hailed a taxi from the Uber app while another took a traditional black cab to the same location, with the route left up to the driver. Black cabs worked out faster, taking on average 88 per cent of the time an Uber did – although they were also around 35 per cent more expensive.

"In London's densest areas, black cab drivers' specialist knowledge gave them the edge in terms of speed"

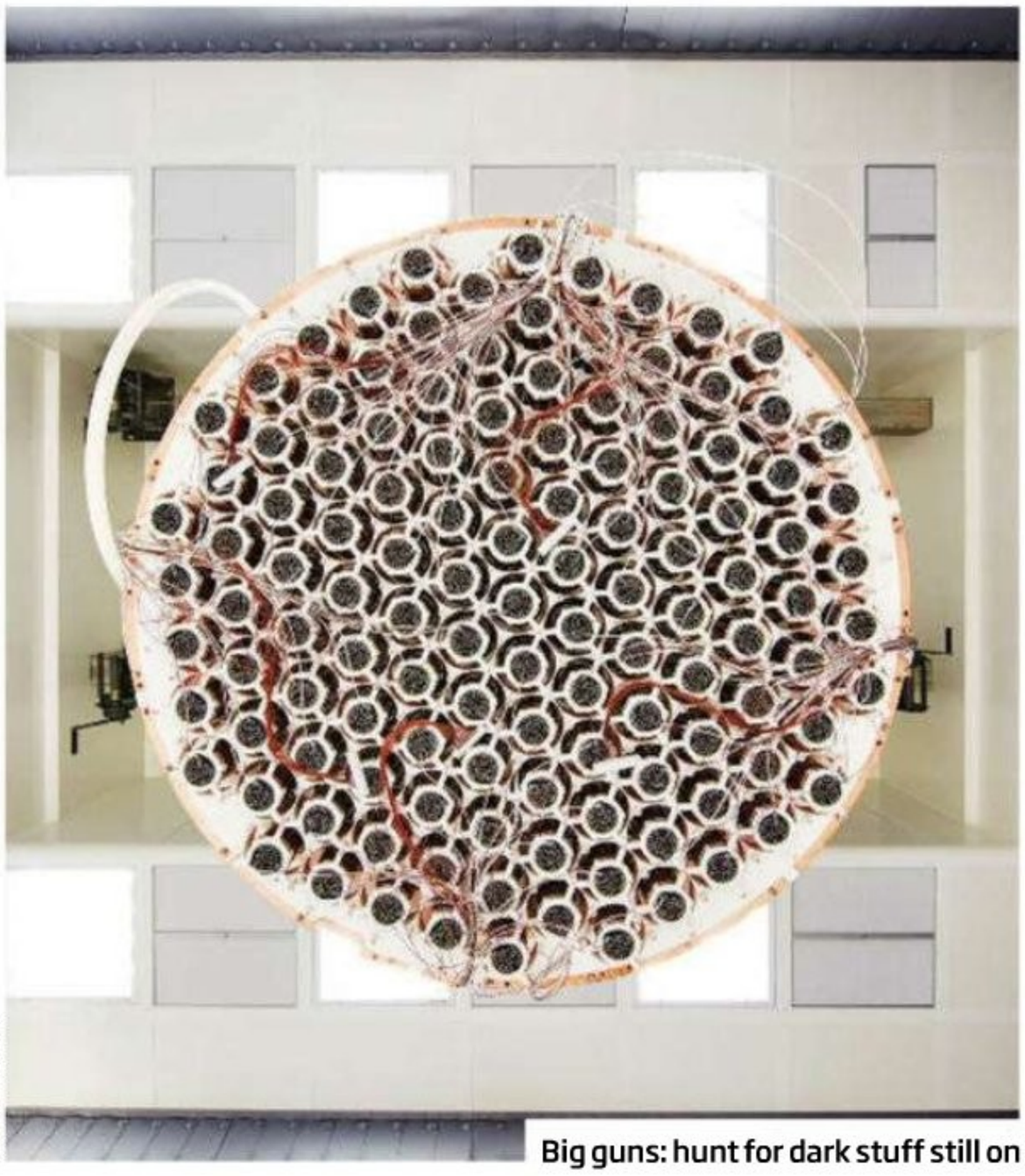
OpenStreetCab is currently available in London and New York and aims to be like Skyscanner for taxis. Comparing prices for taxi services is more difficult than for flights, however, because Uber's prices constantly change depending on demand, and the final cost of any cab depends on the route the driver takes.

Noulas's team found that in London's densest areas, black cab drivers' specialist knowledge gave them the edge in terms of speed. Black cabs had the advantage of using bus lanes (which Ubers can't), but they often took more complex routes. "Uber drivers rely on navigation apps, but in dense parts of the city these can be slower than a black cab driver to react to traffic build up," says Noulas.

The researchers plan to include journey time comparisons in future versions of their app, so that people can make better informed decisions about which service to use.

"The introduction of Uber has made taxi prices less predictable. We're hoping OpenStreetCab will make them more transparent," says Noulas.

Timothy Revell ■



ENRICO SACCHETTI

Big guns: hunt for dark stuff still on

Four-year search fails to find dark matter 'wind'

Jennifer Ouellette

DARK matter has just suffered another blow. Only one experiment claims to have seen signs of the mysterious stuff, and now a massive follow-up experiment has failed to find any evidence for that signal.

We know dark matter makes up about 23 per cent of our universe because of the gravitational force it exerts over normal matter, but it's devilishly difficult to detect.

Myriad experiments have been trying to do just that, most buried deep underground to block out troublesome cosmic rays. But while there have been a few tantalising hints, nothing has reached the threshold required to count as detection – with one exception.

In 1998, scientists at the DAMA experiment buried deep in Italy's Gran Sasso mountain claimed to have bagged dark matter in the form of a WIMP or a weakly interacting massive particle weighing around 10 gigaelectronvolts (GeV). The rate of recorded blips as particles collide with the nuclei of the detector material varied with the seasons. The DAMA scientists attributed this to Earth moving through a dark matter "wind".

"The outlook is starting to look grim for dark matter. Even after one year of data, they should know"

Many physicists argued that other factors besides dark matter could explain DAMA's signal, so for years, other experiments tried and failed to confirm it – including XENON10, also at Gran Sasso.

But in 2011, an experiment called CoGeNT, designed specifically to disprove the DAMA claims, backfired when early results showed a hint of a signal. It disappeared with more data, but the debate stayed alive. An upgraded CoGeNT experiment has been taking new data for the past year, and will publish those results later in 2017, says Juan Collar at the University of Chicago.

Now an upgraded, more sensitive experiment called XENON100, also at Gran Sasso, reports that after four full years of data, they see no evidence for a seasonal modulation (arxiv.org/abs/1701.00769).

Add to this the fact that the upgraded DAMA experiment hasn't announced any new findings since it started taking data in 2013, and the outlook starts to seem a bit grim. "Even after one year of data, they should know," says Laura Baudis at the University of Zurich, Switzerland, a member of XENON100.

So does this mean it's all over but the crying for the controversial claim? Not necessarily.

"It's tough to prove a negative," says Neal Weiner at New York University. But the latest XENON100 results rule out a set of particularly unconventional dark matter models that could have explained the DAMA signal, further constraining probable scenarios.

Baudis admits that if she were part of the DAMA collaboration, she might be getting worried. But she's not concerned about the overall prospects for detecting dark matter, even though two other dark matter experiments – LUX in South Dakota and PandaX-II in China – also reported no signs of WIMPs this week. Our detectors are still quite small, she says.

The next XENON upgrade will have a whopping 3.3 tonnes of liquid xenon, an order of magnitude improvement.

"For me, it would have been a big surprise [to] find dark matter with these small detectors," says Baudis. "So I don't lose hope." ■

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Alert: you're about to catch something

Alice Klein

EVER wished flu would give you advance warning? Wearable tech can now tell when you're about to fall ill, simply by tracking your vital signs.

Michael Snyder at Stanford University in California experienced this first-hand last year. He had been wearing seven body-monitoring sensors to test their reliability, when suddenly they showed abnormal readings. Even though he felt fine, his heart was beating faster than normal, his skin temperature was up, and his blood oxygen level down. "That's what first alerted me that something wasn't quite right," says Snyder.

He wondered whether he might have caught Lyme disease from a tick during a recent trip to rural Massachusetts. When a mild fever soon followed, Snyder asked a doctor for the antibiotic doxycycline, which can be used to treat Lyme disease. His symptoms cleared within a day. Subsequent tests confirmed his self-diagnosis.

Now Snyder and his team have shown smartwatches can do something similar. They got more than 40 volunteers to wear the devices for up to two years, to continuously monitor their pulse and skin temperature.

Unusually high heart rates, and sometimes raised skin temperatures, were seen up to three days before the volunteers had symptoms of a cold or other infection (*PLoS Biology*, doi.org/bw8n). "We think that if your heart rate and skin temperature are elevated for about 2 hours, there's a strong chance you're getting sick," says Snyder.

Continuous tracking of vital signs is more informative than having a doctor compare one-off readings with the average for the population, says Snyder. His team is now hoping to build algorithms to notify smartwatch wearers when they might be falling ill.

"I'm predicting that your smartwatch will be able to alert you before you get sick, or confirm that you're sick if you're feeling a bit off," he says. "If your watch says you're getting something, you'll know to go lie down instead of going out drinking and dancing."

"It's really exciting to consider how much earlier we could intervene to prevent somebody becoming seriously ill," says Meredith Makeham, chief medical adviser to the Australian Digital Health Agency. But Nathan Pinskier, of the Royal Australian College of General Practitioners in Melbourne, says the technology could lead to unnecessary worry. "There's the risk that people will rush off to their GP because they have all these unexplained findings."

Moreover, knowing you might be about to get sick often won't help avoid it, Pinskier says. "If you're going to get the flu, you're going to get the flu." ■

REX/SHUTTERSTOCK

Wrist assessment

Bats that drink bird blood start biting people

HUMAN blood is now on the menu. Wild vampire bats that were thought to exclusively feed on bird blood have been caught feeding on people for the first time, raising health concerns.

Enrico Bernard at the Federal University of Pernambuco in Recife, Brazil, and his team analysed 70 samples of faeces from a colony of hairy-legged vampire bats, *Diphylla ecaudata*, living in Catimbau National Park in north-east Brazil.

They found that out of the 15 samples they managed to get DNA from, three contained traces of human blood. "We were quite surprised," says Bernard. "This species isn't adapted to feed on the blood of mammals."

The bats typically target large birds at night, sucking a spoonful of blood from a single animal as a meal. They are adapted to process bird blood, which is rich in fat, as opposed to the thicker, high-protein blood of mammals.

Previous experiments showed that when only pig and goat blood was available, many bats opted to fast, sometimes starving to death.

But human encroachment may be driving the species to try new blood. The park is now home to several human families and the bat species' usual bird prey, such as guans and tinamous, are disappearing due to deforestation and hunting. Bernard and his team also found that 12 samples contained the blood of chickens, commonly kept on farms in the area (*Acta Chiropterologica*, doi.org/bw8g).

"They are adapting to their environment and exploiting the new resources," says Bernard. In a similar situation, common vampire bats were previously found to start feeding on invasive wild pigs.

The species' new habits are a concern since it could spread disease. Vampire bats are a major transmitter of rabies, and there are often outbreaks in Brazil.

"The bats' new habits are a health concern as they could spread diseases such as rabies"

Daniel Becker at the University of Georgia, who is studying vampire bats, thinks the infectious diseases carried by the species need to be investigated. "Past work has found that it carries the hantavirus," he says. This virus can cause a respiratory disease in humans that can be fatal.

More details about how the bats bite humans will help assess the public health risk. Bernard and his team suspect that they are entering people's bedrooms through holes in roofs or windows, or that they target people sleeping outside in hammocks. The team is currently following up by visiting the homes of local people. "We want to find out how often they are being bitten, when and how," says Bernard.

Sandrine Ceurstemont ■

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Concussion boosts risk of fresh injury months later

SOME consequences of head injuries aren't easy to foresee. They may subtly affect hips and legs, which could explain why athletes who get concussed are more likely to later tear a knee ligament or sprain an ankle.

For up to three months after a concussion, athletes have an increased likelihood of a musculoskeletal injury to a lower limb. "We knew they were more likely to get hurt, but we didn't know why," says Dominique DuBose at the University of Florida in Gainesville.

To find out, her team examined 39 college American football players. Of these, 13 went on to have head injuries. DuBose and her colleagues discovered that for an average of 50 days afterwards, these athletes had stiffer hips but looser knees and legs (*Medicine & Science in Sports & Exercise*, doi.org/bw79). What causes these changes is unclear.

"Stiffness is one of those 'Goldilocks' measures: too much is not a good thing, too little and you're not stabilising your lower extremity," says team member Daniel Herman.

With a better understanding of the relationship between concussion, stiffness and injury, we could improve the way athletes recover from concussion. They might need to undergo more thorough assessment of muscular control and meet stricter health criteria before being allowed to compete again, says Herman.

Laser activates killer instinct in mice

THERE'S a killer inside every mouse. Researchers have found the brain region that controls hunting, and have triggered it using lasers.

Ivan de Araujo at Yale University and his team found that two sets of neurons underpin a mouse's instinct to kill. One coordinates the pursuit of prey, while the other controls the neck and jaw muscles used for biting.

By modifying these neurons so they could be activated by laser light – a technique called optogenetics – the team was able to switch these circuits on whenever they wanted.

When the laser was off, the mice padded around their cages normally. But turning the laser on caused them to suddenly launch frenzied attacks on almost anything in their path: live crickets, fake insects or even sticks and bottle caps. After jumping on the "prey", the mice grabbed it with their paws and repeatedly sank their teeth in (*Cell*, doi.org/bw7m).

The next step will be to determine what activates these two groups of neurons in real life, says de Araujo. "Behavioural studies suggest that visual cues, especially small moving objects, are critical for triggering predatory sequences."

Batteries that put out their own fires

HOW do you stop a phone from bursting into flames? Put a tiny fire extinguisher in the battery.

Lithium-ion batteries are used in portable devices because they are lightweight and efficient, but when they short circuit, their liquid components can vaporise and catch fire.

One way to prevent this is to add a fire-retardant chemical to the battery's electrolyte liquid – but this hinders its performance.

To get around this, Yi Cui at Stanford University in California and his team have enclosed the fire-retardant in a thin polymer capsule. It is only released into the electrolyte if the battery overheats and the polymer shell melts. When tested in burning battery liquid, the capsules extinguished the blaze in less than half a second (*Science Advances*, doi.org/bw9c).

This could make lithium batteries safer for use in electric vehicles and aircraft, says Cui.

Double stars shred their young planets

FOR planets, two stars aren't better than one. NASA's Kepler space telescope showed that most single stars of the same type as our sun have plenty of planets, but only one-third of binary stars do.

Adam Kraus at the University of Texas in Austin and his colleagues developed a model that offers an explanation. When stars pair up, they often gobble nearby rocky material that could have formed new worlds and stir up or fling away what's left, Kraus told the American Astronomical Society meeting on 5 January.

The results suggest that future missions like NASA's planned TESS telescope should keep the search for habitable worlds focused on solo stars.

Molecules set new knotty record

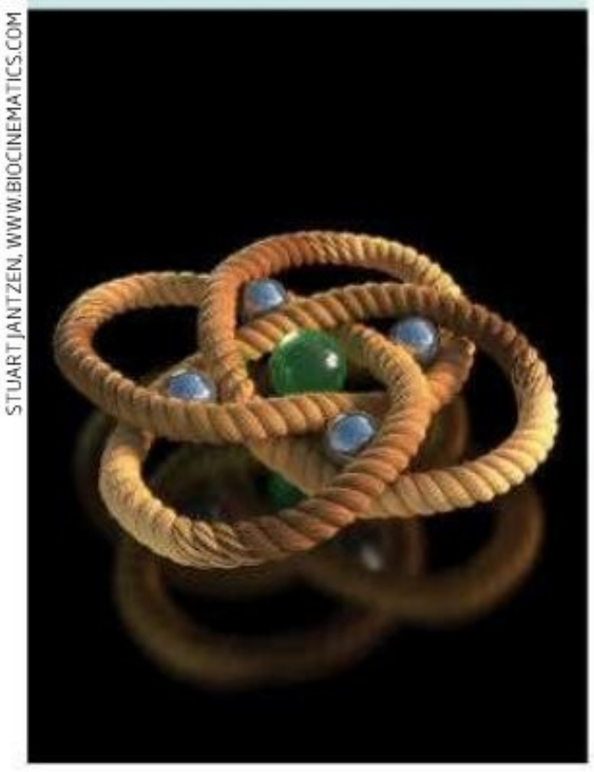
THE most complex knot of its kind is also one of the tiniest. Made of strings of molecules braided together, the knot would only be 20 nanometres long if uncoiled. Many of its properties are unknown, but researchers hope it could one day lead to lighter body armour or more flexible surgical sutures.

Molecular knots are more like knots in mathematics – closed loops in various shapes – than your shoelaces. The first molecular knot, tied in 1989, was a mathematically simple kind called a trefoil. For more than two decades, it was the only knot chemists could make.

"It was pretty pathetic," says David Leigh at the University of Manchester, UK. In 2011, Leigh was part of the first team to create a molecular pentafoil knot, with strands crossing over one another five times, versus a trefoil's three.

Now Leigh and his team have synthesised a knot with eight crossings, making it the most complex of its kind ever tied (*Science*, doi.org/bw8h). They used a precise mix of ions under controlled conditions to braid the strands of molecules together. The final knot contains 192 atoms.

"This is a synthetic masterpiece, formed in a very simple and extraordinarily elegant manner," says Thorfinnur Gunnlaugsson at Trinity College Dublin, Ireland.



STUART JANTZEN, WWW.BIOCINEMATICS.COM

Fish lure snails to their nests to help camouflage their babies

APPEARANCES can be very deceptive. Look closely at brown-striped lake snails and you may spot one that is actually a fish.

"Often I confused the fish young with snails," says Shun Satoh at Osaka City University, Japan, who studied cichlid reproduction in Lake Tanganyika in eastern Africa.

The cichlid, *Neolamprologus furcifer*, raises its brood in rocky nests near the lake shore – a habitat shared with various snail species. Satoh found that the baby fish had the same brown-and-white stripes as the most abundant snail in the nests, *Reymondia horei*. The baby fish resemble them in size, shape and even posture, in what appears to be the first known case of fish masquerading as snails.

However, it's not the babies that benefit from this deception, but their mothers. When Satoh removed the snails, baby fish survival stayed the same. But this was only because, with the snail smokescreen gone, the female fish seemed to work even harder to keep their offspring alive by driving predatory fish away (*Animal Behaviour*, doi.org/bw73).

Female cichlids also chase off harmless algae-eating fish. The researchers suggest that this behaviour may have evolved as it attracts snails to the nests by ensuring they have a plentiful supply of algae to eat.

But some snails lack the stripes the baby fish mimic, and the team saw female cichlids remove non-striped snails from their nests, effectively giving the striped ones more space to colonise and make the masquerade more effective.

Ants farm seeds to unlock nutrients

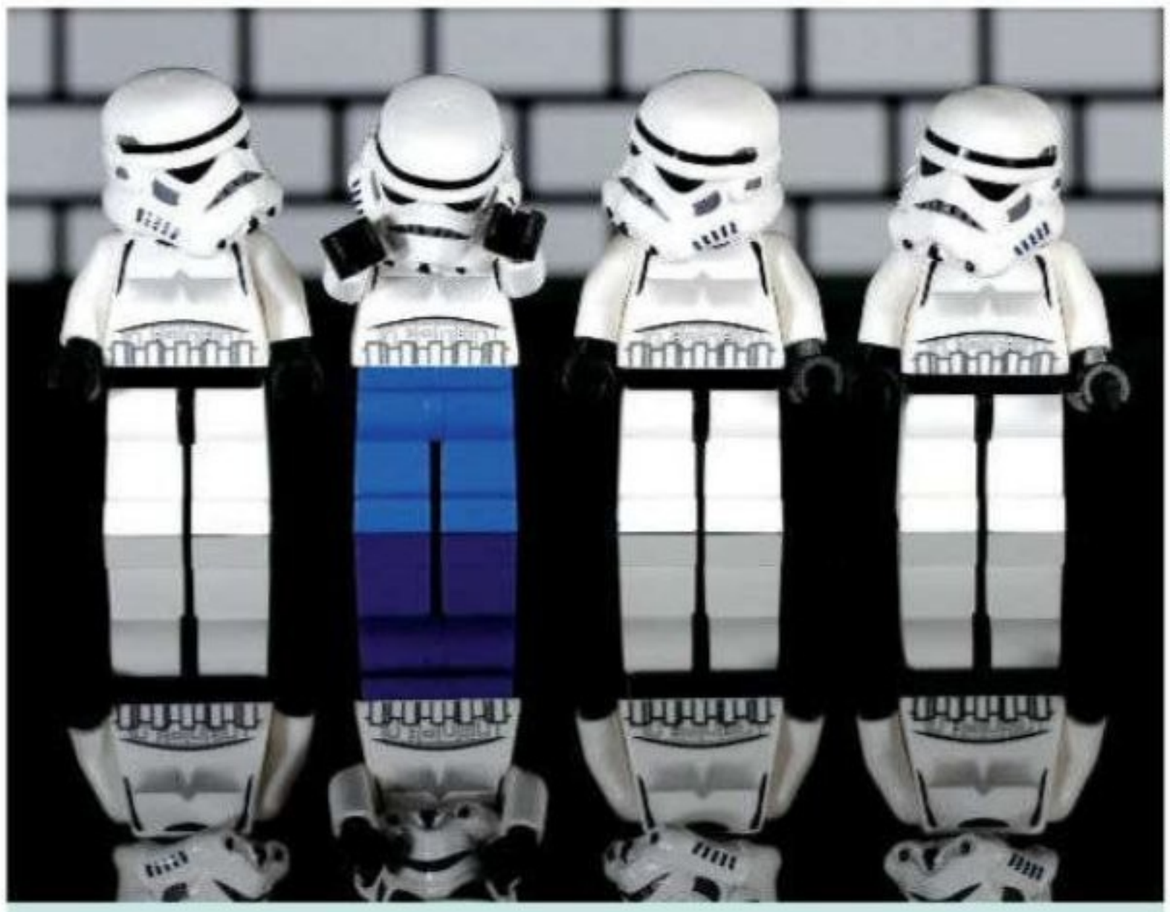
THEY'VE cracked it. Small ants carry home large seeds to eat, but no one knew how they broke through the seed's tough exterior.

It turns out that Florida harvester ants, *Pogonomyrmex badius*, have developed a clever farming strategy – they plant seeds, wait for them to germinate and then eat the soft spoils.

Some 18 genera of ants harvest seeds, and colonies of some species can store more than 300,000 seeds in their underground granaries.

Until now, the ants were thought able to break into the seeds and eat them as they were. "The reality is a lot more interesting," says Walter Tschinkel at Florida State University in Tallahassee. With his team, Tschinkel excavated and studied some 200 *P. badius* nests and then carried out a range of experiments.

The group found that the ants mostly open and consume small seeds, which are easier to crack, and keep larger ones until they germinate. Germination splits the tough husk, making the seed contents available as food for the ants and their larvae (*PLoS One*, doi.org/bw8s).



ANDREW WELLS/GETTY

Not the bots you're looking for

COMPUTER scientists recently felt a disturbance in the force. They found a Twitter botnet – possibly containing more than 350,000 accounts – that has tweeted thousands of quotations from the *Star Wars* books.

Shi Zhou and his research student Juan Echeverria Guzman at University College London stumbled upon the bots lurking within six million randomly selected English-language Twitter accounts. When they plotted their tweet locations on a world map, a strange pattern appeared. More than 3000 were within two uniform rectangles, with many clearly having fake coordinates as they appeared to be from deserts or ocean.

"When we manually looked into the accounts, we noticed that [their tweets were] just random quotations from *Star Wars* novels," says Zhou.

A machine-learning algorithm trained to identify further *Star Wars* bots found almost 357,000 matches (arxiv.org/abs/1701.02405).

No one knows who set up the bots or why. Jon Crowcroft at the University of Cambridge says it may simply have been an experiment by an amateur hacker. "It's amusing," he says, "but it's relatively pointless."

CHARLES OMMANNEY/THE WASHINGTON POST VIA GETTY IMAGES

Respect my authority

What's the worst that could happen?

President Trump will be inaugurated on 20 January. We don't yet know what a Trump presidency will look like, but some of the policies he and his team have already floated would have irreversible ramifications for everything from climate to nuclear weapons to reproductive rights. And protesting such moves is about to get much more difficult

Sally Adee

WELCOME to the new normal. Even before Donald Trump was elected, the US was already in a "golden age of surveillance".

As Edward Snowden revealed in 2013, the US government's surveillance powers had expanded dramatically under the Obama administration. Trump has repeatedly signalled that he intends to make much greater use of these capabilities – perhaps inspired by British legislation that has given the UK government unprecedented power to snoop on its citizens.

In both cases, such powers were ostensibly introduced to combat terrorism. But there's very little evidence that greater spying powers actually catch terrorists, many of whom already know how to evade spooks. On the other hand, there is mounting concern among privacy advocates and human rights campaigners that such powers will stifle domestic dissent and enable political witch-hunts (see page 5).

"It's not the government you have now that's the issue," says Harry Halpin of the World Wide Web Consortium. "It's the government you might have in the future. In the US, everyone said, well the NSA isn't so bad, Obama is such a rational guy. Now we have Trump wanting to create a database of Muslims."

So how will the state's creeping expansion of its eavesdropping capabilities affect the right to protest? The UK's Investigatory Powers Act – known as the "snoopers' charter" – goes far beyond what even the US has made legal, granting government authority to force internet service providers (ISPs) to collect information on their users, and the ability to hack into devices on very broad warrants.

Most people are not against the idea of targeted surveillance to bring down terror plots, for example, says Adrian Kennard who runs Andrews & Arnold, a

small, privacy-oriented ISP in the UK. The problem is, the UK's targets are not "targeted" at all – the focus could be "everyone in Manchester", Kennard says. "Or they might decide to target everyone connected to a BT broadband line."

Trump is certain to take inspiration from the UK, says Danny O'Brien of the Electronic Frontier Foundation in San Francisco. The US and UK are already planning to weaken the protections on cross-border access to data, he says, allowing UK law enforcement to seize communications from Google and Facebook without a US warrant – and vice versa.

Whether or not he pushes for new rules, Trump is very unlikely to roll back any existing measures. No one else will, either. Overreach in other spheres could plausibly be reversed in future, but powers of surveillance are in political terms nearly impossible to roll back: not only are they seductive, but no government wants to be accused of being soft on security.

At risk

Legal challenges to such powers are being mounted on both sides of the Atlantic. But the bottom line is that online privacy looks set to be fatally eroded.

So what's really so bad about Donald Trump and UK prime minister Theresa May riffling through your computer and your communications? After all, if you're not a terrorist, you have nothing to fear, right?

This view is desperately naive, says Halpin. "If you think you have nothing to hide, you probably do," he says. "And if you think you haven't broken any laws, I promise that you have."

One concern is that poorly framed or antiquated laws can be used as a pretext to prosecute or harass anyone who falls foul of ›

Climate scientists fight Trump's chilling effects

THE climate forecast for the next four years is bleak. Donald Trump notoriously tweeted in 2012 that global warming was a hoax created by China to damage US manufacturing. As president-elect, he has chosen a climate change denialist to head the Environmental Protection Agency, and his pick for the helm of the energy department (DOE) is Rick Perry, who once suggested dismantling it.

If CO_2 emissions rise faster as a result, the consequences for the global climate will be dire. "We can't take a four-year break," says Marcia DeLonge at the Union of Concerned Scientists (UCS) in Washington DC.

But a Trump presidency won't just be a problem for climate change – it could also spell trouble for the scientists trying to stave it off.

In December, the Trump transition team asked for a list of DOE employees and contractors who worked on climate change or had attended climate change meetings. The agency refused, but the incident has sent a chill through the scientific community, particularly in the light of the Republicans' revival of the Holman rule, which means specific federal employees can have their pay slashed to $1, effectively dismissing them.

Climate scientists' fears of being targeted are legitimate. There has already been an uptick in Freedom of Information Act requests for their private emails, says Peter Fontaine, the lawyer who defended climate scientist Michael Mann in a high-profile case against the State of Virginia. If such tactics also came from within their own agencies, federal scientists might leave en masse.

Peter Frumhoff, director of science and policy at the UCS in Cambridge, Massachussetts, says this would permanently erode federal agencies' ability to use science to inform policy decisions. His message to scientists is unequivocal: "Please don't leave," he says. "If you leave we'll lose your ability to know what's going on."

But if they do stay, they may be forced to stop pursuing certain lines of research anyway. The Trump transition team suggested as much when it said NASA should shift its focus away from "politically correct environmental monitoring".

Fears that data could be misused or altered have prompted crowd-sourcing to back up federal climate and environmental data, including Climate Mirror, a distributed volunteer effort supported by the Internet Archive and the Universities of Pennsylvania and Toronto.

Can that work be done elsewhere? Several programmes are trying to decentralise the process of collecting new data. Even before the election, NASA was planning a programme to buy Earth science data from commercial CubeSats, shoebox-sized satellites that can be built and launched cheaply. "We can do really serious science with CubeSats now," MIT's William Blackwell told the American Geophysical Union (AGU).

At a pinch, some agency-level work could be done by individual states. "If Trump turns off the satellites, California will launch its own damn satellite," California governor Jerry Brown told the AGU meeting. "We're going to collect that data."

One unexpected consequence of a Trump presidency is that it may spur more scientists to advocacy. Many are already circulating petitions and open letters, and organising groups. "We don't want to be here. We want to be doing the work we were trained to do," said Naomi Oreskes at Harvard University at a protest rally during the AGU meeting. "But we are at a moment in history where we have to stand up." Lisa Grossman ■

BEATING THE HEAT

How can scientists protect themselves when their work comes under political fire?

Peter Fontaine at the Climate Science Legal Defense Fund recommends that researchers at public universities get to know their legal counsel, so that the school will back them if a suit is filed. Further legal assistance is available from organisations like Fontaine's.

He also advises that scientists practice good email hygiene, writing them as if they'll be shown in court, and scrupulously keeping personal and work emails separate. And adding a footer noting that the contents are exempt from freedom of information laws – if they are – may help too.

AP PHOTO/MARCIO JOSE SANCHEZ

You can count on us

› powerful interests – much as they have previously been used to prosecute hackers.

In the US, one such law could be the arcane Computer Fraud and Abuse Act, created in 1986, which makes it a federal crime to access a computer in a manner that "exceeds authorized access". Companies have occasionally used the CFAA to bring civil suits against competitors, but the real threat goes far beyond that, because it can criminalise violations of websites' terms of service – even something as trivial as lying on a dating website, says Esha Bandari, a lawyer with the American Civil Liberties Union, which is challenging the law.

Whether violations are pursued is "at the mercy of prosecutors' discretion," she says. Just because they haven't exercised that discretion until now doesn't mean they won't: "That makes the law open to discriminatory enforcement," she says.

In this light, what is dangerous about bulk data collection is that it makes fishing expeditions possible, says Jim Killock from the UK's Open Rights Group. All this data is kept somewhere, forever. "They can search and process that data to get new and interesting material, and decide whether you're a suspect for something. It's quite chilling," he says.

Is this possible to avoid? "The answer is not to have the data in the first place, so there's nothing to store," says Ben Laurie, head of security at Google DeepMind, who is also a director at the Open Rights Group. Security experts point to the Tor network, which anonymises and encrypts your trail through the internet. But it might not be so simple. "Under the IP act, using Tor will put a target on your back," says Killock. Trump's proposed CIA boss has called the use of encryption a "red flag". Once flagged, bulk hacking powers include a provision to break into your device and slurp up its contents.

A "virtual private network" might seem a better idea, but only

Women turn to Plan B on reproductive rights

AT THE very top of the hit list for the resurgent Republican party is the Affordable Care Act, better known as Obamacare. The ACA has extended health insurance coverage to an extra 7 per cent of Americans since 2014, but Republicans, with Donald Trump's support, have already started the complex job of repealing it.

While it is not clear what will replace the ACA, it is likely that one area of healthcare will see major changes. Contraception and abortion are hot-button issues for the conservative and evangelical voters who make up a large part of the Republican base, if not necessarily the American public at large.

Obamacare made contraception completely free under most insurance schemes. Its rule that people under 26 could stay on their parents' policies helped younger women – who might not previously have had insurance – get access to contraception.

Both the provision of contraception and the under-26 rule are now in doubt, although Trump has signalled his desire to preserve the latter in any successor to the ACA. Republicans are also trying to crowbar in a measure to pull federal funds from Planned Parenthood, a charity that provides free or subsidised family planning services to people on low incomes.

Republicans have been gunning for Planned Parenthood for years, because it provides abortions as well as contraception. A push to raise donations is gathering pace, but it's doubtful if this can replace the entire federal budget contribution of over half a billion dollars, some 40 per cent of the charity's income. A shortfall is likely to force the charity to close clinics or restrict services.

UNEXPECTED ALLIES

Faced with the prospect of losing control of their reproductive rights, some women are taking pre-emptive measures. Online campaigns have begun urging women to get fitted with the coil – a form of birth control that can last five years or longer. Planned Parenthood has reported that requests for the coil have been running at nine times their normal level since the election.

Trump has also vowed to appoint supreme court justices who will overturn the landmark ruling that enshrined the right to abortion at a federal level. He may well have the opportunity, since several of the justices are elderly and so vacancies may open up over the next four years. If that happens, individual states will decide whether to permit abortion – meaning it will probably be banned in conservative states such as Louisiana and Kentucky.

MANDEL NGAN/AFP/GETTY IMAGES

Keep it legal

Women on Web, a charity which sends abortion pills to women in countries where a termination is illegal, is now considering extending its efforts to the US. Another organisation, the National Network of Abortion Funds, suggests that women in need of an abortion should travel to Mexico to buy the stomach ulcer pill misoprostol at pharmacies there.

"Requests for long-acting birth control have risen by 900 per cent since the election"

When using it in a routine two-step medical abortion, a woman would normally take a second drug, mifepristone. However, misoprostol alone is still 80 to 85 per cent effective at ending a pregnancy of less than 12 weeks, says the NNAF.

The possibility of having to go to such lengths may be one reason there are now anecdotal reports of women stockpiling morning-after pills. That's also down to fears the administration will try to revoke its over-the-counter status, which was granted during Obama's tenure. This is something conservatives fought the Food and Drug Administration over for years. Its status is anything but guaranteed.

Changing a medicine's legal status for political reasons rather than safety fears would be unprecedented – but not impossible. And while most government policies are reversible when the political wind changes, any unwanted pregnancy changes at least one life permanently. Clare Wilson ■

if you are choosy about which one you use: not all will keep your data away from governments. Switzerland, for example, might be a good place to stash money, but has a data-sharing agreement with the US. VPN providers based in the Netherlands or Germany offer stronger protection under their national privacy laws.

And even the most secure VPN is going to do little good if the computer you are using is open to attacks. The Apple ecosystem is generally more likely to protect privacy; while Google's security is excellent, its implementations vary by hardware. That makes an iPhone a better bet for security than an Android device.

The software you use matters, too. Secure chat services may not be that secure. Whether or not Telegram was really hacked by Russian authorities, Halpin says his group has also broken the protocol. WhatsApp also appears vulnerable. "I recommend people use Signal," he says. "It's the most reliable and secure peer-reviewed text messaging app."

"Trying to evade snooping by using Tor or encryption might put a target on your back"

As for email, Halpin suggests using RiseUp.Net, if you are concerned about snoopers. "They have no history of complying with requests for email. Lots of high-risk people go there," he says.

The rest of us could do worse than Gmail. "Google has been resistant to court orders it finds overreaching," claims Laurie.

Even if civil society has trouble mobilising against a surveillance state, all is not lost. Even now, Halpin says the W3C and other groups that run the infrastructure of the internet are teaming up with companies like Apple and Google to bake these security enhancing protocols in by default. "Making encrypted software easier for the average person to use is a civic responsibility," he says. The real resistance may just be getting started ■

US NAVY PHOTO / ALAMY STOCK PHOTO

Bringing a nuke to a gun fight

The return of Dr Strangelove

FROM the moment Donald Trump is inaugurated on Friday, he will be accompanied constantly by a device that launches nuclear missiles within 4 minutes – widely known as "the button". Is it safe under his finger?

Many have been worrying about that question ever since Trump first seemed likely to become president. His mercurial nature and contradictory policy statements make him an unpredictable custodian of the US nuclear arsenal.

The stakes are high. "The use of even a single nuclear weapon, anywhere in the world, would be a global humanitarian, environmental and economic disaster," says Derek Johnson, head of anti-nuclear group Global Zero, for reasons ranging from nuclear winter to a lowered threshold for subsequent nuclear attacks.

But even if Trump never does press the button, he could permanently alter the geopolitical landscape by relaunching nuclear proliferation.

On 22 December he tweeted that the US "must greatly strengthen and expand its nuclear capability", which he has called "broken". In fact, reviews have found the technology itself is fine. Nonetheless, the US is launching a $35 billion-per-year modernisation programme, while Russia has already started a nuclear upgrade. "We seem to be sleepwalking into this new nuclear arms race," warns veteran nuclear official Bill Perry. That could push smaller nuclear powers to expand as well.

"Every apocalypse has a silver lining – a Trump presidency may limit some nuclear threats"

As planned, modernisation will mean building next-generation nuclear weapons. This would deal the final blow to the tottering Nuclear Non-proliferation Treaty, which tells nuclear powers to disarm, not re-arm. New weapons also need testing, which would kill the 1992 nuclear testing moratorium and the 1996 Comprehensive Test Ban Treaty.

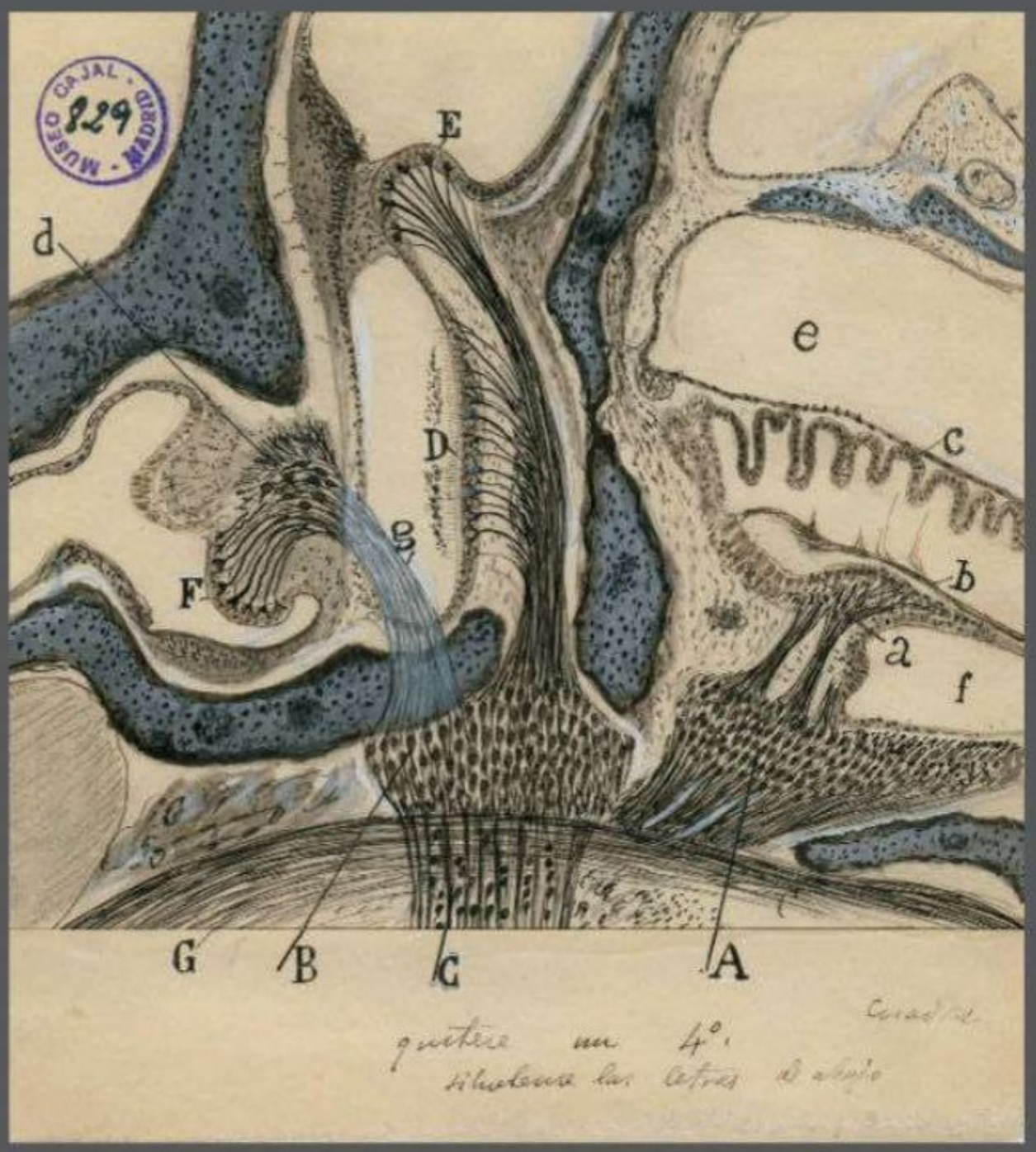
This would also encourage more countries to go nuclear, such as Japan, which has plutonium and is thought capable of building a bomb in months. And after Trump's hints that the US may not continue to guarantee the security of long-standing allies, "Iran, Saudi Arabia, Turkey and Egypt might decide that they can defend themselves only by acquiring nuclear weapons," warns Nouriel Roubini at New York University.

The biggest risk is Iran. Trump has called the 2015 agreement under which Iran promised to limit its nuclear activities "the worst deal ever negotiated" and has promised to "dismantle" it – leading scientists to protest that its loss would lead to more conflict in the Middle East.

But he could also limit some nuclear threats. North Korean leader Kim Jong-un, who is expected to greet the inauguration with missile or nuclear tests, made real progress towards a deliverable weapon in 2016. Trump tweeted that "it won't happen". And it might not: Trump has said he is prepared to talk with Kim. Talks have worked before, halting North Korean weapons development in 1994 – until their cessation let it resume.

Trump could also take US missiles off alert, the status which makes "the button" so dangerous. His apparently close relationship with Russia has led some to hope he might deactivate this relic of the cold war: in fact, this week he suggested the US could lift sanctions on Russia in exchange for joint nuclear arms reductions. What will he suggest next week?

Debora MacKenzie ■



Draw to attention

SANTIAGO RAMÓN Y CAJAL was always a rebel. Born in Spain in 1852, as a youngster he ignored his father's pleas to follow a career in medicine and instead pursued his own interests – drawing, bodybuilding and photography, to name just a few. The photograph to the left is one of his many self-portraits. He even built his own cannons, and played multiple games of chess at the same time.

He eventually became interested in medicine after working with his father to produce anatomical drawings. In the 1870s, as microscope technologies advanced, he became fascinated with the inner workings of the body's cells.

Ramón y Cajal adapted a technique of staining cells to view them under a microscope, and used this to create many drawings, as well as theories on how the brain works. For example, he proposed that neurons in the brain don't form a single, connected network. Instead, he believed they are separate and individual, but ready to communicate with each other. This discovery formed the basis of modern neuroscience, and Ramón y Cajal is often referred to as its father. He was awarded a Nobel prize in 1906 for his work on the nervous system.

Pictured top right is Ramón y Cajal's drawing of the inner ear – a labyrinth of structures that pick up sounds and detect how the head tilts and rotates. This information is sent to the brain via the neurons labelled A and B.

Below this is a drawing of the hippocampus, a brain region involved in memory that, in this case, was taken from a man three hours after his death. In it, Ramón y Cajal has illustrated several star-shaped astrocytes. These cells support other cells in the brain, and here they "hug" the larger, pale grey neurons.

A collection of drawings by Ramón y Cajal are featured in the book *The Beautiful Brain* published this month by Abrams and edited with commentaries and essays by leading neuroscientists. Jessica Hamzelou

Images

Santiago Ramón y Cajal
Courtesy Instituto Cajal del Consjo Superior de Investigaciones Científicas, Madrid, © 2017 CSIC

Infinite frontiers

We're finally working out how to navigate our way through the multiverse, says **Shannon Hall**

SOME of your doppelgängers mimic your every thought and action, only with a snazzier haircut. Some live in a world where the Nazis won the second world war, or where the dinosaurs survived, or where things fall up instead of down. Not here. Not in this universe. But they are out there – in the multiverse, where every possible world exists, along with all the infinite versions of you.

Travel any distance in modern fundamental physics and you will soon find yourself in the multiverse. Some of our most successful theories, from quantum mechanics to cosmic inflation, lead to the conclusion that our universe is just one of many. "It's proven remarkably difficult to come up with a theory of physics that predicts everything we can see and nothing more," says Max Tegmark at the Massachusetts Institute of Technology.

So where are these unseen universes in relation to ours? How many are there? What goes on inside them? And can we ever hope to visit one? Such questions might sound daft, particularly given the lack of observational evidence that the multiverse exists. And yet thanks to new ideas on where distant universes might be hiding or how to count them, physicists are beginning to get their bearings. Rather fittingly, though, there is not just one answer – depending on which version of the multiverse you're navigating, there are many.

The journey into this confusion of worlds starts in our own. The universe we call home was born from the big bang some 13.8 billion years ago, during which time light has travelled further than you might expect – 47 billion light years, thanks to the universe's ongoing expansion. This is the limit of what we can see, because light from more distant reaches would not have had time to reach us yet. But we're pretty sure space-time stretches further, perhaps to infinity.

Past the cosmic horizon is a patchwork quilt of separate universes like ours, all bound by the same laws of physics. At least that's the assumption: those laws don't change over the distances we can see, so there is no reason to think they will suddenly transform beyond them. The only real differences are in the details: any intelligent life out there might live in a solar system that contains five planets instead of eight, say, or two suns.

"There's not just one answer to how the multiverse looks – there are many"

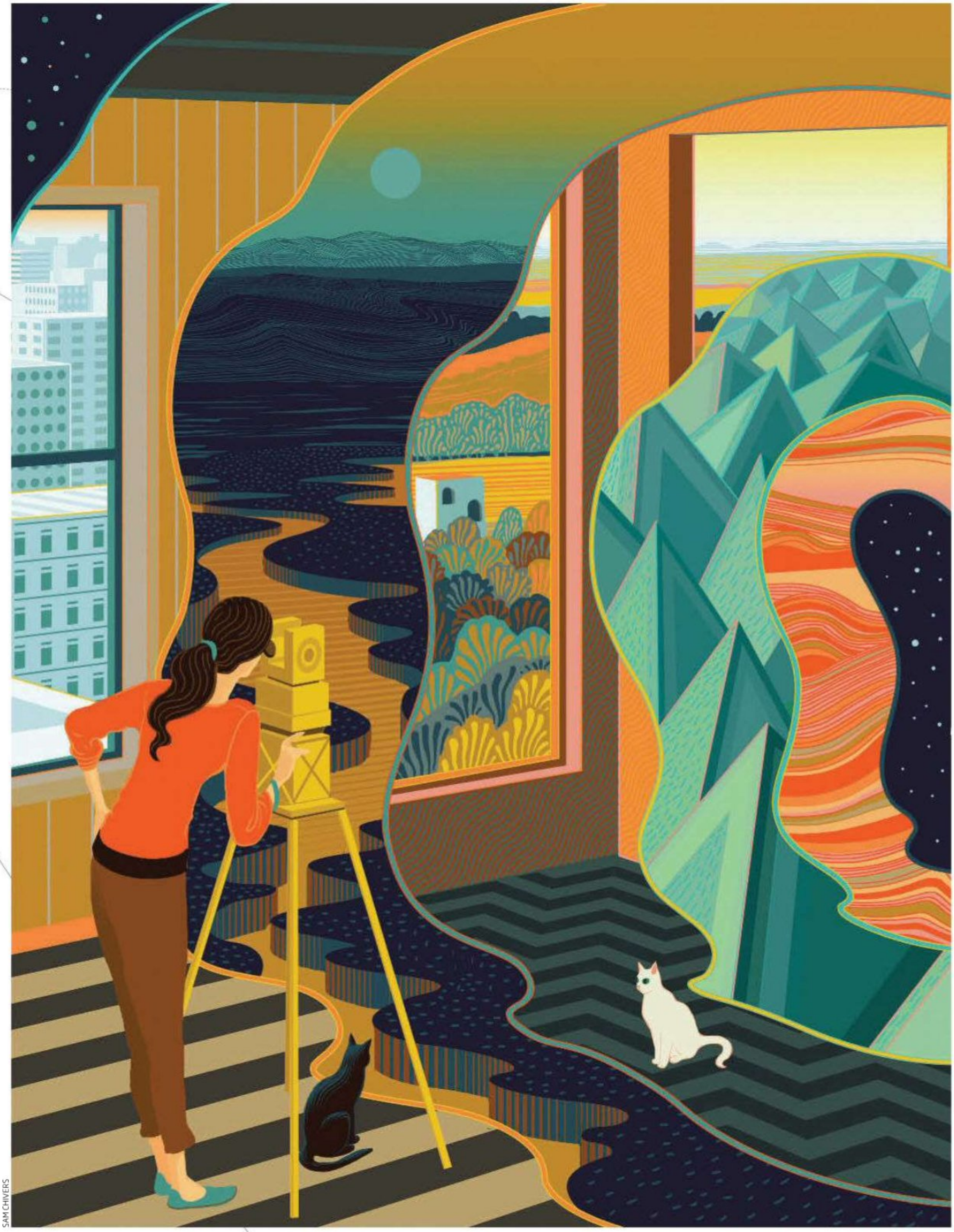
What are the chances those details are exactly the same, to the point where there's another version of you? Tegmark thinks it's entirely plausible. Assuming space stretches on forever, then there are an infinite number of patchwork universes, and everything allowed by the laws of physics will happen – more than once. He has even calculated the distance you would have to travel to meet your doppelgänger. It's a 1 followed by a hundred thousand trillion trillion zeros.

For many, though, this is just the first step. The expansion of the multiverse beyond the patchwork version started with a theory devised by Alan Guth, a cosmologist at MIT, in 1980. He proposed that in the first split second following the big bang, the early universe underwent a stupendous growth spurt, expanding by a factor of 10^{25}. This exponential ballooning, known as inflation, is beloved by cosmologists because it fixes several major problems with the big bang story.

In one guise, known as eternal inflation, the theory has space-time expanding exponentially forever, but with quantum effects that stop the ballooning in small regions. Our universe grew up in one of the resulting bubbles, and the same happened elsewhere. What's more, these quantum effects continue today, fuelling an endless froth of bubbles, each containing a universe.

Exactly where each bubble emerges is random. Picture a table of haphazardly placed billiards balls: one of those balls is our universe, and the others are additional universes separated by space-time. Then forget that picture. The analogy falls apart when you remember that each ball is growing as each universe expands, the table is stretching as the fabric between universes continuously inflates, and more balls are popping up at random as quantum effects spawn more universes. That's a spooky game of snooker.

Wherever they pop up, it's possible that these bubble universes – unlike those of the patchwork multiverse – contain physics gone wild. In 2000, Joseph Polchinski of the University of California at Santa Barbara and his colleagues threw string theory into the ›



SAM CHIVERS

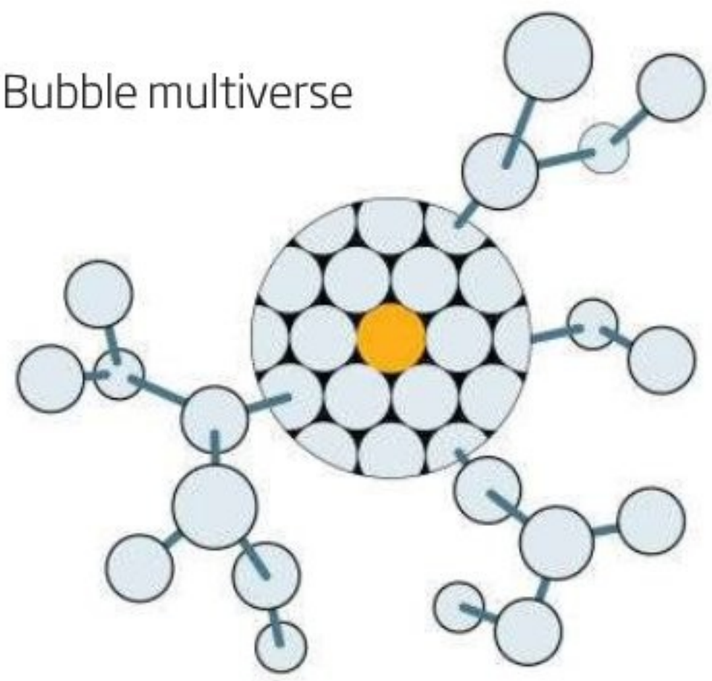
Where are we?

Finding our place in the multiverse means deciding which version we live in

Patchwork multiverse

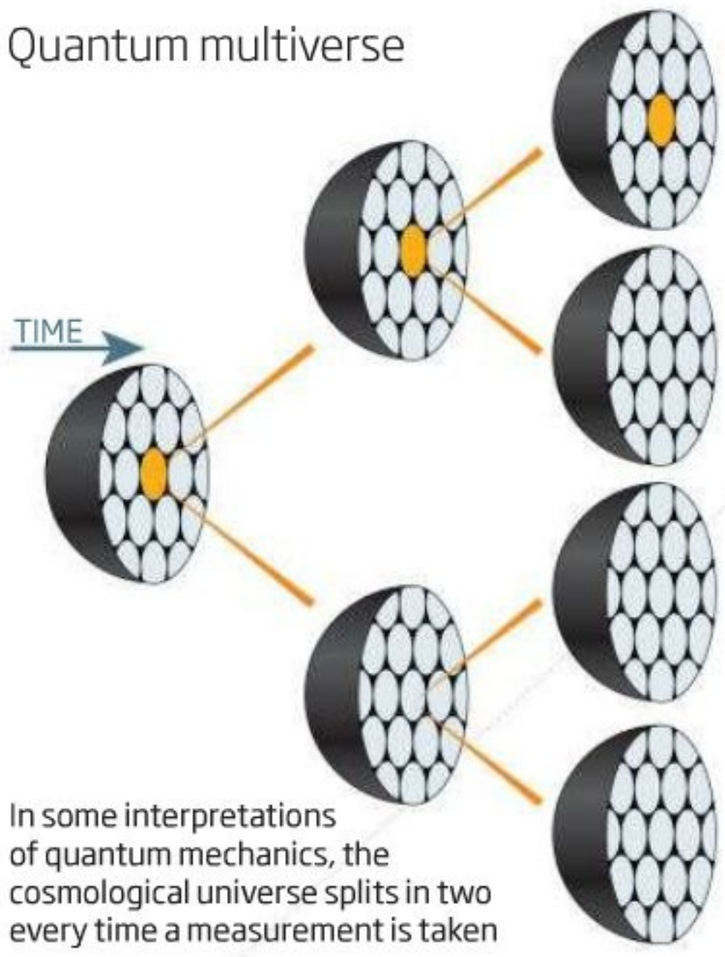
Beyond the limit of what we can see is a patchwork quilt of what are essentially separate universes

Bubble multiverse



If the rapid explosion of space-time carries on forever, infinite bubble universes could pop out of the patchwork multiverse

Quantum multiverse



In some interpretations of quantum mechanics, the cosmological universe splits in two every time a measurement is taken

mix. The result gives rise to universes drastically different from our own, where unfamiliar laws of physics act on unimaginable particles. "It's the multiverse on steroids," says Alexander Vilenkin of Tufts University in Medford, Massachusetts.

The reason is that string theory, a comprehensive but untested theory of nature, operates in 10 dimensions – six more than the ones we know so well. These extra dimensions are scrunched up into unimaginably small spaces. In our universe, they form a particular configuration, which determines the properties of our particles and laws of physics. But they can form at least 10^{500} different configurations, which means an infinite number of universes can fall into that many categories, each with different particles and laws of physics. Basically, anything goes.

These bubble universes would be largely unrecognisable. Photons might outpace our speed of light, for instance, and apples might fall upwards from a tree's branch. They would also be inhospitable to us, because the stability of atoms depends on a certain balance of the constants in our theories, says Sabine Hossenfelder of the Frankfurt Institute for Advanced Studies in Germany. "So if you go to another universe, it might also have areas of stability for atom-like things, but they would be very different from ours… Probably what would happen is that you would decay immediately."

And even if there is another universe conducive to our sort of life, it would be well beyond reach – more distant than in the patchwork multiverse. "You could never get there even if you travelled at the speed of light forever because you would have to travel through a piece of space that is still inflating and doubling in size like crazy," Tegmark says.

Cosmic hidey-holes

Or maybe there is a shortcut. At least, there was. Last year, Vilenkin and his colleagues suggested that other universes might be nestled within the black holes that formed during the first second of our universe's existence. The idea is that small patches of space-time shifted into a different quantum state, forming tiny bubbles. Then, when inflation ended, those bubbles collapsed to form primordial black holes. But in the largest of these black holes, inflation continued, creating baby universes.

Vilenkin's theory predicts a distinctive distribution of black holes. Should this match the distribution of black holes in our universe, which we have only begun to chart, we'll have proof that this multiverse exists. We would even discover the mass a primordial black hole must have to contain another universe, potentially pointing us towards other universes dotted around the night sky.

We could never visit them, or could we? Nikodem Poplawski of the University of New Haven, Connecticut, and his colleagues also think that black holes harbour hidden universes, but these ones might still be attached to our own. They came up with the idea in an attempt to revise Einstein's theory of general relativity, which indicates that there are "singularities" at the heart of black holes that take up no space but are infinitely dense and infinitely hot. This aspect of the theory has always been hard to swallow. Even Einstein himself thought that singularities could not exist in physical reality.

If Poplawski is correct, they don't. According to his theory, the matter within a black hole doesn't collapse to a single point, but instead hits a barrier before bouncing back. "But it cannot go back outside the black hole, which means the matter has to create a new space," Poplawski says. "So the black hole becomes a doorway to a new universe."

The natural conclusion is that our universe was also formed within a black hole in another universe – an idea that sheds a rather different light on our beginning. "The big bang is replaced by a big bounce," says Poplawski. This origin explains our universe's expansion and does away with the need for inflation. In a study out last month, Poplawski even calculated that our parent black hole is probably a billion times the mass of the sun, on a par with the supermassive black holes that lurk in the centres of most massive galaxies.

That's not to say we should picture our universe as being within a universe, like a cosmic Russian doll. "It's not the same physical space in some sense – it's more like a parallel universe," says Damien Easson of Arizona State University in Tempe, who has made a similar speculation. "It really would be a different universe altogether, occupying a different part of the multiverse."

You might, however, be able to reach it via a shortcut through space and time known as a wormhole. If this multiverse were represented by billiard balls, they would be connected with invisible tunnels, and they'd all be different sizes, growing at different rates. Some would form further black holes, which in turn create more universes, themselves connected by invisible tunnels to those that created them.

With both the patchwork multiverse and the various bubbly versions, you can imagine them as contiguous – next to each other, or at least connected, even if the laws of physics in our universe mean you can't get from one to another. Not so for another sort, the worlds of the quantum multiverse. These are superimposed into the same space we occupy and are at once more intimate and more distant.

Since the 1920s, physicists have been baffled by quantum mechanics, which suggests that a particle can exist simultaneously in two or more possible states of being. So an electron, for example, can be in two places at once – until someone measures it. At that point, the electron has to "choose" one particular state. But what about the other state?

In the 1950s, Hugh Everett, then a graduate student at Princeton University, came up with the idea that all of these potential states are equally real – they simply exist in parallel universes. Suppose, for instance, that you conduct an experiment in which you measure the path of an electron. In our universe, the electron travels in one direction, but the measurement creates another universe where the electron travels in the opposite direction.

In the quantum multiverse, then, every measurement creates another universe that is folded into our own yet is invisible and inaccessible.

That's too outlandish for some. The main problem, says Michael Hall of Griffith University in Brisbane, Australia, comes from confusion over what constitutes a measurement. Does it have to be a physicist doing a quantum experiment? Or could it be every decision we ever make? Everett's theory doesn't have the answers, so his many worlds remain fuzzy and the number of universes is impossible to count.

"Ultimately, all the different multiverses could co-exist, but which one came first?"

Fed up with the uncertainty, Hall and his colleagues have come up with a new scenario called "many interacting worlds". Unlike Everett's original idea, it begins with a finite number of universes, all similar to ours in size and scope, superimposed on our universe. Here, quantum events are produced as a result of particles from one of these universes interacting with those from another.

Take quantum tunnelling, where particles defy ordinary physics by tumbling through an energy barrier as though it isn't there. If an electron is heading towards a barrier in our world, it might interact with an electron heading towards that same barrier in a parallel world. The particles will start to repel one another, causing one to give the other an energy boost so that it can achieve the unimaginable: it will break through the energy barrier.

Merging the multiverses

In Hall's theory, the probability of the electron breaking through is slightly different to the probability predicted by standard quantum mechanics. That's good news – in theory, the deviation is measurable and could tell us how many parallel universes we're dealing with.

But even if quantum many worlds do work in this way, how do they fit with the various cosmological multiverses? Hall thinks that his quantum multiverse and the inflationary multiverse can exist simultaneously, but argues that one has the upper hand. "There is, in essence, only one super quantum multiverse," he says. That's because inflating space-time creates new universes from small quantum effects, and in order for those effects to exist there must already be a quantum multiverse.

Others think that if more than one theory pans out, the inflationary multiverse probably came first. Once the frothing sea of inflation started churning up new bubble-like universes, a few would have created black holes, which formed more universes. Or perhaps those universes might branch off into other universes with every quantum measurement. "If this interpretation is correct, then the eternally inflating multiverse will constantly split into a multitude of eternally inflating copies," Vilenkin says.

Ultimately, there is nothing to say that all these different multiverses couldn't co-exist. Some theorists even think that Everett's many worlds and the inflationary multiverse might actually be one and the same. Although they look different, they both constantly branch into new universes, says Leonard Susskind of Stanford University in California. And such an odd characteristic should not be taken lightly.

"Maybe they are different sides of the same story," says Susskind. If so, the pioneers surveying the multiverse might finally agree that we only need one map to find our way. ■

Shannon Hall is a science writer based in New Hampshire

MAYA DE ALMEIDA ARAUJO/PLAINPICTURE

Out of breath

Complex life could never have evolved without oxygen – or could it? **Colin Barras** investigates

AT THE bottom of the Mediterranean Sea, just south of Greece, there is a lake. Complete with a delicate shoreline and an inviting deep blue surface, the L'Atalante basin looks almost like a lake on land. But this is an inhospitable place. Its waters are about as salty as water can be and never mix with the layers above – making it completely devoid of oxygen.

It was a shock, then, when biologist Roberto Danovaro scooped up samples from the bottom of this briny pool and found a thriving community of microscopic animals living there. The discovery went against everything we thought we knew about animal life and its reliance on oxygen.

Some biologists still think Danovaro must have made a mistake. Yet his is just the most exotic in a series of discoveries that are chipping away at our long-held beliefs about the importance of oxygen to complex life. We thought anything beyond the simplest cell couldn't do without it. But now we're finding that some animals can carry on more or less happily with the merest whiff of the stuff.

It's a finding primed to upset our tidy story of why complex life evolved on Earth. Nick Butterfield, a palaeontologist at the University of Cambridge, puts it bluntly: "Atmospheric oxygen has nothing to do with it." He reckons there is a much simpler explanation – one that's been staring us in the face.

For the first 80 per cent of our planet's history there was barely any oxygen, and no complex life either. That has always seemed perfectly logical. Organisms that use oxygen to respire can squeeze as much as five times more energy from the sugar in their food than those that use sulphur or other substances. That makes oxygen a gateway gas to a vibrant world where organisms have enough energy to become anatomically interesting. Plants are a different and more complicated story, but the consensus has been that multicellular life with specialised tissues – animals in other words – only evolved when there was enough oxygen.

The link seems to make sense geologically too. When we reconstruct the past concentration of oxygen in Earth's atmosphere from geological samples we get a story in which the gas was hardly around for aeons, then rose a tiny bit before flatlining again. It only jumped up substantially about 800 million years ago – not long before we see the first fossils of complex life (see "Breath of life", page 35). To many geochemists, that cannot be a coincidence.

But not everyone feels this way, and there has been plenty of grumbling. As early as 1982, Bruce Runnegar at the University of New England in Australia estimated that some of the earliest animals in the fossil record might have had incredibly low oxygen demands. He calculated that ancient 1-metre-long worms needed so little oxygen that they could potentially have lived billions of years before that jump in concentration 800 million years ago.

Those were worms, and theoretical worms at that. But in 2014, Daniel Mills and Donald Canfield at the University of Southern Denmark in Odense set about investigating how much oxygen real primitive animals need. They began by collecting living breadcrumb sponges from well-oxygenated water off the Danish coast, a relevant test ›

MARK NEWMAN/FLPA

Absolutely gasping: carp can survive for months without oxygen

case because sponges are one of the earliest animals to have evolved. Then the researchers carted them back to their lab and did their best to suffocate them.

Over several days they reduced their oxygen supply, first to 70 per cent of current atmospheric levels, then 50 per cent, then eventually to 5 per cent. Even then, the sponges clung to life, with one even seeming to grow slightly (*PNAS*, vol 111, p 4168). It suggested that Runnegar's calculations pointed the right way: simple animals could have coped with ancient oxygen levels. "Sponges require vanishingly small amounts of oxygen. It's a fact," says Butterfield.

"I think there's a distinction to be made here between eking out a living and thriving," says Timothy Lyons, a geochemist at the University of California, Riverside. Some of today's simpler animals might be able to endure low oxygen levels, but for all we know that makes for a grim existence. Lyons thinks it is unlikely that evolution would have selected for animals that could barely soldier on.

A comfortable sponge

The crucial question, then, is how comfortable the sponges are. To find out, we need a sense of how they fare biochemically when they don't have much oxygen, says William Martin, a biologist at the University of Düsseldorf in Germany. That means studying their mitochondria, the seat of cellular energy production.

Mitochondria use oxygen to help make a molecule called ATP, which cells use as a fuel. That is how our own cells work, but some animals have developed ways of coping when oxygen runs low. Their mitochondria can conduct a super-efficient form of oxygen-free sugar fermentation to stay alive. A carp, for example, can function without oxygen for four months if its pond gets covered in ice. But as far as we know it can't carry on indefinitely. If the sponges exist in a similar stand-by mode it lends weight to Lyons's misgivings.

Mills is busy investigating what is going on inside the sponges' mitochondria in an attempt to clarify things. "We actually don't know yet," he says. But fermentation is not the only way ancient animals might have thrived without oxygen. Take protists, the earliest form of our own eukaryotic lineage, which evolved when oxygen was barely around at all. Although protists have only one cell, their insides are far more complex than bacteria. Some of them seem to have powered this extra complexity with modified versions of mitochondria called hydrogenosomes, which work in the absence of oxygen. Might more complex eukaryotes have done the same?

That is where L'Atalante might be relevant. Danovaro's team, from the Polytechnic University of Marche, Italy, became interested in the site partly because it is such unique environment. Danovaro began studying it in 1998 out of curiosity about what might live there.

More than he bargained for, was the answer. When he and his team lowered a weighted scoop and pulled up sediments from the lake bottom they found multicellular animals from a little known group called loriciferans. Assuming contamination, Danovaro returned to the site twice more – but kept on finding them.

He also found plenty of other animals, including nematode worms and tiny crustaceans. But these seemed to be rotting carcasses, and he concluded they had probably drifted down from oxygenated waters above, settling on the surface of L'Atalante before eventually sinking into it.

"Either the animals are alive or being eaten from the inside by bodysnatchers"

But the loriciferans were different: they looked pristine. And they acted as if alive, taking up a fluorescent dye absorbed only by creatures with a working metabolism. When Danovaro looked at the animals under a microscope, he saw structures the size and shape of mitochondria but without their telltale internal architecture – hydrogenosomes in his estimation.

That's not enough to convince those in the know. "Identification by sight of which organelle is involved – mitochondria or hydrogenosome – isn't easy, if possible at all," says biochemist Aloysius Tielens, who studies hydrogensomes at Utrecht University in the Netherlands. It's through their behaviour that hydrogenosomes are properly identified, which means studying the loriciferans' biochemistry while they are alive.

That's rather an ask. It's not even clear that the loriciferans can survive the journey from their high-pressure habitat to a ship. Danovaro's fluorescent dye experiments suggested they might, but aren't definitive.

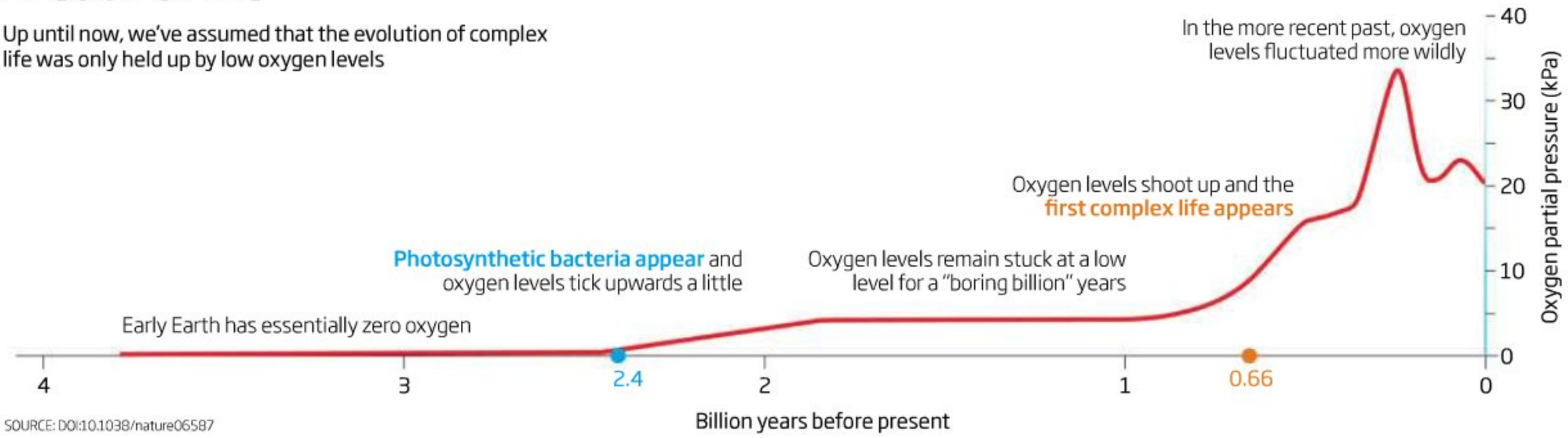
Then Virginia Edgcomb of the Woods Hole Oceanographic Institution in Massachusetts had an idea that might at least settle whether the loriciferans were living in the lake. "Our game plan was to recover specimens that looked intact and then try to extract messenger RNA from them," she says. This ferries genetic information around cells and breaks down rapidly, so finding it would show the animals were alive recently.

Edgcomb and her colleagues visited L'Atalante to give it a try, but quickly ran into a snag. They had opted to use a remote-controlled submersible called Jason to take samples rather than Danovaro's crude scoop. But the salty lake was so dense that the sub couldn't dive into it. Like the collection of plastic bags and tin cans that the sub's camera saw accumulated on the lake's surface, "Jason was too buoyant," says Edgcomb.

Cutting her losses, she set about exploring the oxygenated mud around the shores of the lake. In 2015, she reported that loriciferans live there too, lending support to the idea that they merely fall into the pool after death. What about the fluorescent dye that supposedly

Breath of life

Up until now, we've assumed that the evolution of complex life was only held up by low oxygen levels



SOURCE: DOI:10.1038/nature06587

shows the animals were alive? Edgcomb thinks it could be explained by bodysnatcher bacteria, which don't need oxygen, eating the dead loriciferans from the inside out.

For his part, Danovaro stands by his original claims, though he admits proving it is going to be a challenge. Another mission to L'Atalante with the right equipment to catch living loriciferans on camera would help settle things. But for now the question of whether animals can thrive, rather than just survive, without oxygen remains in stalemate.

Whatever the truth about the loriciferans, more people are beginning to accept that what Butterfield calls the "oxygen explains everything" narrative fails to tick all the boxes in its description of why complex life evolved. With conclusive evidence in short

Breadcrumb sponges can grow in almost oxygen-free waters. But are they happy?

SUE DALY/NATUREPL.COM

supply, Butterfield thinks it's time to consider an alternative. "The reason that animals appeared so late in the day is very simple," he says. "They are extraordinarily complex and it took a long time for evolution to discover them."

Evolution has invented multicellular organisms relatively few times, says Butterfield – and what he calls "truly complex" multicellular life has evolved just twice, giving us animals and land plants. Plus, animals were the only branch of the eukaryotic tree to turn multicellular as oxygen levels began to climb 800 million years ago. If a rise in oxygen was the only barrier to their evolution, why didn't more eukaryotic branches follow suit? The atmosphere has been rich in oxygen for hundreds of millions of years, after all.

Even the "coincidental" rise in oxygen at the time of the first animal fossils looks different through the prism of evolution, says Butterfield. He points out that animals are profound ecosystem engineers. So filter-feeding sponges, for instance, would have pumped enormous quantities of water through their bodies every day, feeding on the plankton it contains. With fewer plankton sucking up the oxygen in the ocean water, more of the gas would be available to power complex organisms on the seafloor – which is where early animals lived and breathed. Put simply, Butterfield reckons the sponges could have caused a rise in oxygen levels, not the other way around.

There is, however, an elephant that may yet trample on Butterfield's idea: the whopping uncertainty over what oxygen levels actually were in the distant past. Our reconstructions are based on ancient marine sediments and fossil soils. Analyse their chemistry and you can deduce what was going on in the atmosphere when they formed. Except they might not always be reliable. The soils, for instance, were almost certainly home to microbes that would have influenced how much oxygen was stored. The consensus is that around 800 million years ago oxygen concentration was somewhere between 1 and 20 per cent of what it is now. But some calculations suggest it was as high as 40 per cent.

In an effort to help pin things down, Lyons, together with Noah Planavsky at Yale University and Chris Reinhard at the Georgia Institute of Technology, have tried using a shiny new method involving chromium. How much of this metal is stored in rocks depends on how much oxygen was in the atmosphere when they formed. But instead of clarifying the picture, the trio have further fogged it up. Their chromium record indicates that between 1.8 billion and 800 million years ago, oxygen rarely rose above 0.1 per cent of the present levels – lower than anyone thought possible.

"It's a controversial dataset," admits Lyons. Yet if it contains any truth, it's a boost for the traditional view of oxygen limiting the evolution of complex life. Few would argue that even the simplest animals could have thrived on such meagre supplies.

Even though the story isn't yet resolved, the disagreements mask a deal of common ground. "I'd like to think there's a shift towards a more nuanced view of the oxygen story," says Butterfield. And this nuanced view has ramifications far beyond the evolution of life on Earth. A whiff of oxygen in an exoplanet's atmosphere was long seen as a hint that complex life is more likely to be found there. These recent results give the lie to that more than ever. So if we do find an inhabited planet one day, will it be veiled in a cloud of oxygen? Don't hold your breath. ■

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EMILIANO PONZI

– Mending minds –

Cell therapies will soon allow us to truly rebuild broken brains, says neurobiologist **Jack Price**

A FEW months ago, Evelyn Hilton was able to ditch the walking stick she had relied on since 2014 and stand on her own two feet again. Meanwhile, Sonia Olea Coontz felt her right arm "wake up" after more than six months of it being totally paralysed and was able to walk more easily. Both had taken part in clinical trials in which stem cells were injected into their brains at the site of an earlier stroke.

This was no "Lazarus effect"; the patients didn't wake from surgery and leap dramatically from their beds, totally cured. Yet the results were a major step forward in efforts to heal damaged brains, and could lead to such treatments becoming widely available within just a few years.

It is undoubtedly an exciting time for stem cell medicine. Stem cells, the blank slate from which the body can build any type of cell it needs, are proving themselves capable of doing what was once thought impossible: healing broken brains. Yet having followed the progress of cell therapies since the 1980s, it seems to me that this technology is just the beginning of a wave of even more exciting potential treatments. They would involve persuading the diseased brain to replace its lost cells without the need for a transplant: a true regenerative medicine of the brain.

Brain injuries present the body with a unique problem. While most other tissues can repair themselves when damaged, the adult brain, with the exception of two small regions, cannot make new neurons from scratch. There is a short window of time after injury when the brain attempts to clear away debris and reroute its connections to regain some of the lost function. Some drugs, if given within a few hours, can stop the damage from becoming too severe. Even so, the fact that dead neurons can't be replaced can mean that the damage done leads to lifelong disability.

The idea of restoring brain function by transplanting new cells into people's brains predates the possibility of stem cell medicine. In the 1980s, two Swedish people with Parkinson's disease were given brain grafts of dopamine-producing cells from the adrenal glands. The cells lost in Parkinson's disease use dopamine as a neurotransmitter, and although the adrenal glands are located far from the brain, above the kidneys, they too make dopamine. The idea was that if

> "The adult brain cannot normally make new neurons from scratch"

dopamine was needed, perhaps it wouldn't matter what kinds of cells were providing it. Initial results from animal studies looked encouraging, but grafts in humans had little effect on symptoms and the approach was soon abandoned.

Other researchers tried using dopamine-producing nerve cell precursors taken from aborted fetuses. The approach was controversial, but because the implanted cells were closer to what is lost in Parkinson's, patients seemed to fare better.

Almost 100 people have had these kinds of transplants in trials over the past two decades, and follow-up studies show that in many cases the cells are alive and the patients still showing benefit 20 years after the transplant. It seemed to be the breakthrough we had been waiting for in the treatment of neurodegeneration, and the future looked bright. I remember predicting at the time that cell therapies would be widely available within five years.

That didn't happen, for several reasons. First, when larger trials were done including a control group who had the surgery but had no cells injected, it turned out that, overall, fetal cells performed no better than placebo. What's more, the older, more severely affected patients got the least benefit from the surgery. The treatment also proved logistically, as well as ethically, difficult. Each transplant required material from three or four aborted fetuses, meaning that many people would never be comfortable with the procedure. It was also clearly never going to be possible on any practical scale.

Similarly, efforts to genetically engineer the enzymes needed to produce dopamine into various other cell types have yet to succeed, despite several decades of experimentation and animal studies. All in all, by the early 1990s, it looked as if replacing brain cells with a rough approximation of what had been lost just wasn't going to work.

Fortunately, stem cells were just starting to show promise in the lab, and this changed the game. Symptoms of Parkinson's disease may well be alleviated if a few hundred thousand dopamine-producing neurons could be replaced. But stem cells, with their ability to generate various cell types, held the potential to fix many more kinds of brain damage. Brain tissue is composed of many different kinds of cells, including neurons, support cells, connective tissue and blood vessels. The earlier attempts at cell replacement had shown it was possible to squirt cells into an injured brain without causing further damage. The question now was whether ›

stem cells could get in there and rebuild the complex structure of what had been lost.

Again, animal studies looked promising. Rats injected with stem cells following a stroke recovered sensation and movement to a degree rarely seen before. On closer inspection, though, there was a surprise. The reason it worked wasn't because dead and dying cells had been replaced with shiny new ones, although this did happen to some extent. Even when stem cells remained in their immature state and didn't differentiate at all, they still contributed to recovery. In many cases, the implanted cells didn't even survive for more than a few weeks, but still the animals showed significant recovery.

What seems to be happening is that stem cells release growth factors and other chemicals that stimulate the brain to heal itself, potentially giving compromised circuits the ability to regroup and reorganise. Some of these chemicals may also boost the immune system, reducing inflammation and helping to stimulate blood vessel growth – all crucial if a newly mended bit of brain is going to thrive. In fact it could even be that this plays a more important part in brain fixing than cell replacement.

> "Patients have a hole drilled in their skull and a slurry of cells is gently squeezed in"

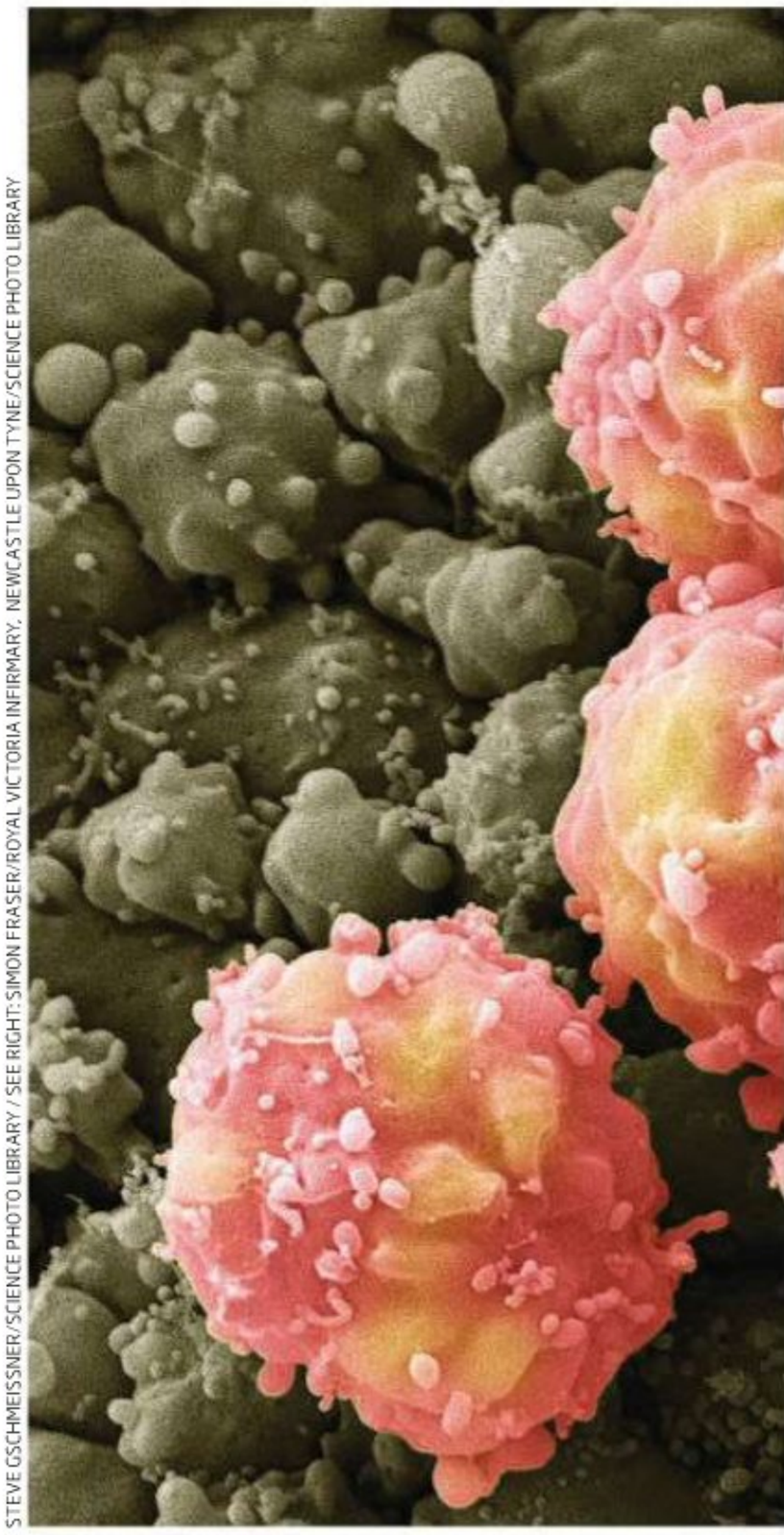
So far, though, no one knows for sure what the stem cells are doing in the brain, and this has led some to argue that even if it works, we should hang back from using it on patients. Some researchers think it would be unethical to proceed; others think it would be unethical not to.

Whatever the rights and wrongs of that argument, clinical trials are under way. In the past two years, two companies – ReNeuron in Pencoed, UK, and SanBio in Mountain View, California – have reported on their phase 1 clinical trials using stem cells to improve disability following stroke. Both have reported good safety data, and intriguingly, the first glimpse of efficacy.

In the ReNeuron trial, on which I acted as a consultant, fetal stem cells were processed using a technique that allows a single neural stem cell to generate enough cells to treat hundreds of patients. The SanBio technology starts with a different kind of stem cell, derived from bone marrow, but engineered in such a way that it maintains its stem cell characteristics.

Once the cells have been prepared, the technique for getting them into the brain is remarkably crude. Under anaesthetic, patients have a hole drilled in their skull, and using brain imaging to guide the surgeon to the site of injury, a slurry of cells is gently squeezed in. Remarkably, this procedure has proven relatively safe and easy, and most patients in the trial were able to go home within a day or two. Some reported temporary headaches, and some had local bleeding or fluid accumulation. One patient had a seizure, probably associated with the surgery, but neither trial revealed safety issues attributable to the cells.

Not all of the patients had the dramatic improvements that Hilton or Coontz experienced, but the majority showed significant improvement in control over their limbs, or had other life-changing

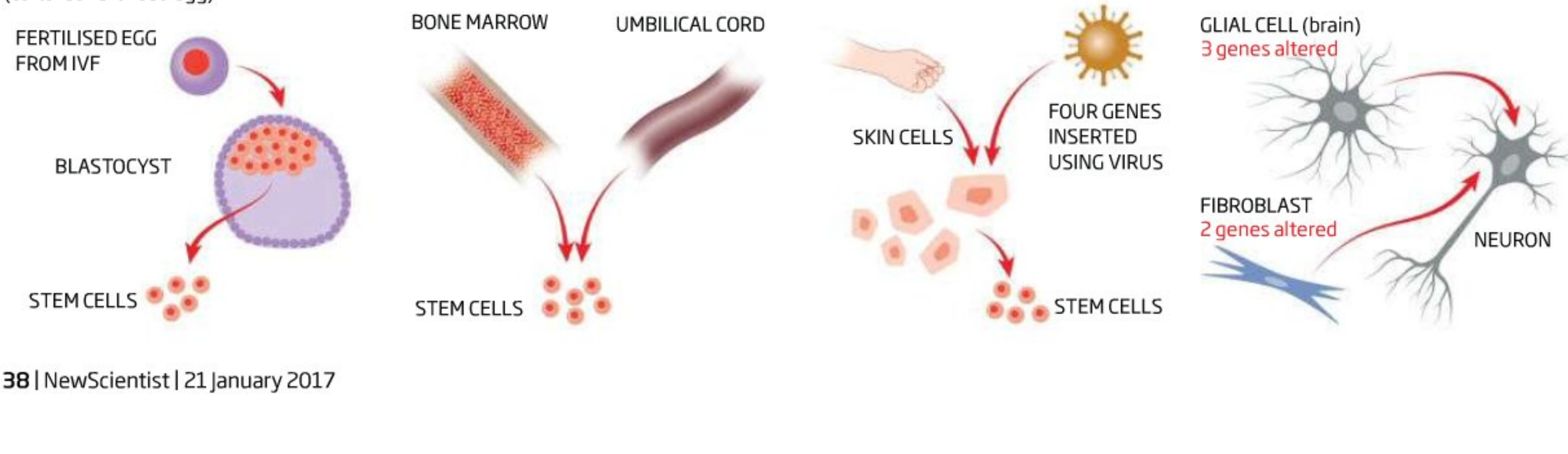


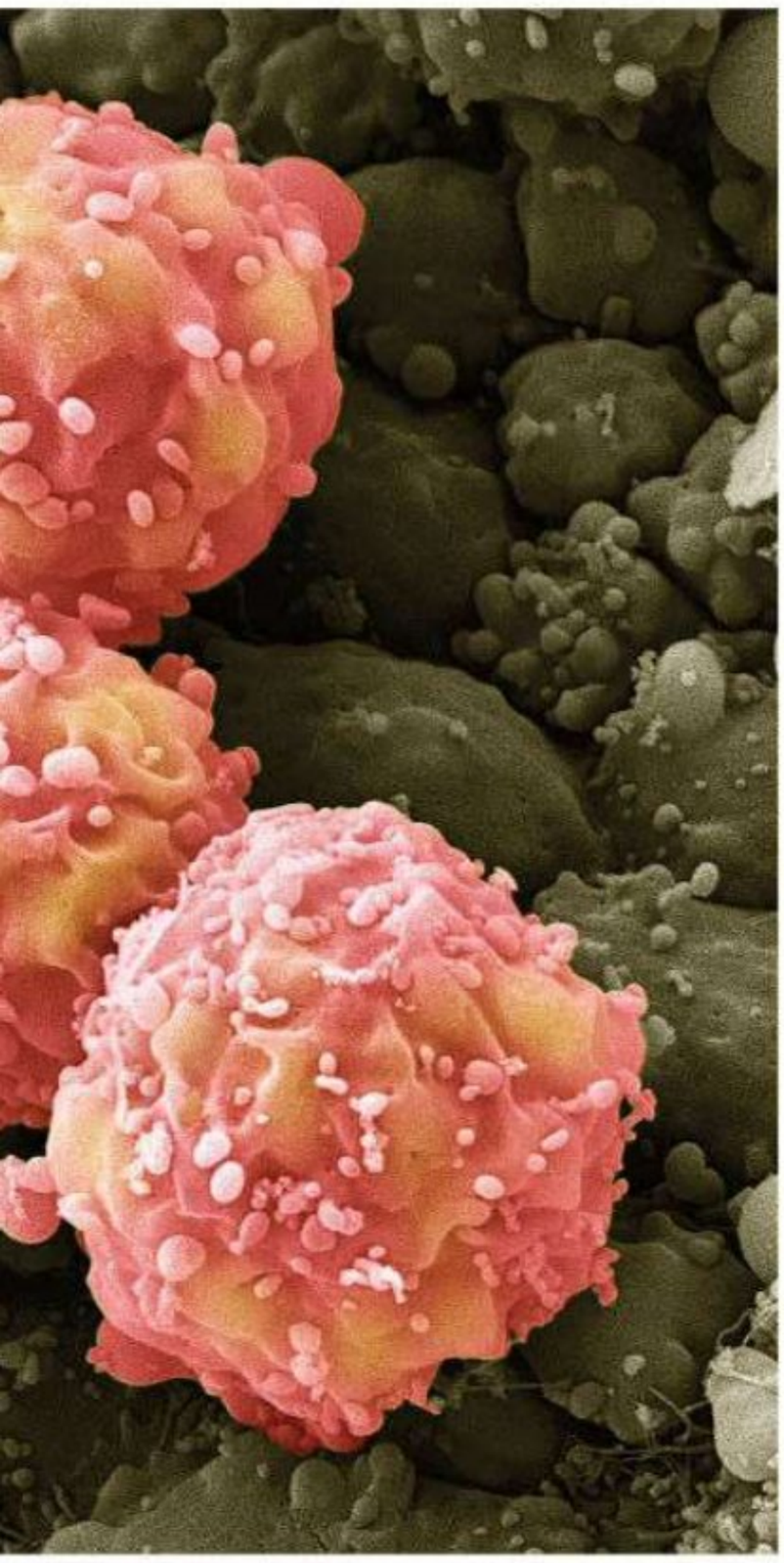
STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY / SEE RIGHT: SIMON FRASER/ROYAL VICTORIA INFIRMARY, NEWCASTLE UPON TYNE/SCIENCE PHOTO LIBRARY

Besides being able to develop into any cell type in the body, stem cells (above) may help persuade damaged areas to bounce back, augmenting the brain's capacity for self-repair following a stroke (right)

Easy cells

There are three ways to source stem cells for transplants. Direct cell conversion could save us the hassle by letting us make the cell type we ultimately want – such as neurons





improvements such as the loss of a tremor. And despite the cells themselves only lasting a month or so after the injections, the improvements seem to linger way past the six months after which stroke patients are usually told to expect no more change. "It's two and a half years on from when I had the stroke and I am still having improvement," says Hilton. "It's slow, but it's still happening. I don't regret getting it done at all."

Even small changes can have a big effect. Being able to move a limb or just a thumb can mean the difference between being able to take the top off a bottle yourself and needing to ask for help.

These successes have set the stage for larger clinical trials. SanBio is recruiting patients for phase 2 trials. The interim results of ReNeuron's phase 2, reported in December 2016, look broadly promising, with the final results expected in 2017. If successful, these trials could herald a stem cell treatment for stroke within five years, although larger controlled trials would still be required before the treatment could be licensed by regulators. Other researchers are trying to introduce the cells sooner after the stroke to limit the damage rather than repair it, although it is too early to say whether this approach will prove superior.

Critics point out that even if this turns into a successful treatment, it won't be the cell-replacement therapy originally envisaged, and some argue that we should hold off until we can deliver on that promise. That reality, however, may not be too far behind.

A key step towards this goal came in 2006, when Shinya Yamanaka of Kyoto University in Japan discovered a way to wind back the clock of adult cells to a point normally encountered only at the start of development, when embryonic cells have the potential to become any kind of cell in the body. The creation of these induced pluripotent stem cells (iPS cells) from cells derived from adult connective tissue won him the 2012 Nobel prize in medicine.

It is difficult to exaggerate the impact of Yamanaka's discovery on stem cell research. After that it was possible to start with essentially any human cell – blood, skin, hair – and reprogram it into a stem cell. This discovery immediately alleviated the ethical and logistical pressure on deriving stem cells from human embryos, and Yamanaka's iPS cells quickly became the cell of choice for regenerative medicine applications.

Although still a little way behind, therapies based on iPS cells are approaching clinical trials, and are increasingly seen as the future of cell transplants. What's more, unlike the current technologies, these iPS cells can actually build new tissue from scratch.

The logical next step would be to hop directly from one cell type to another, without going via stem cells. Better still would be to do it directly at the site of injury. Both of these would have seemed crazy a decade ago, but now look like distinct possibilities (see diagram, below left). In 2010, Marius Wernig at Stanford University in California and his colleagues showed that it is possible to tweak the activity of just three genes to change a

> "The right combination of factors gives the brain the chance to repair itself"

fibroblast, a cell type found in connective tissue, into a fully functioning neuron. In 2014, Magdalena Götz at the Munich Center for Neurosciences – Brain and Mind in Germany, and her colleagues demonstrated not only that is it possible to convert support cells in the brain into neurons, by changing the activity of just two genes, but that it can be done in the brain of a living animal directly at the site of damage. The trick here is that some of these support cells have hidden stem cell potential. The right combination of factors coaxes these properties to show themselves, giving the brain an opportunity to carry out repairs.

The key then will be specificity. Neurons come in many different types, more than we can even count accurately. If you want to replace what was lost, you need the right type for the job; as the Parkinson's experiments showed in the 1980s, not just any old cell will do. Can we come up with precisely the right recipe to generate a specific neuronal type?

It is a way off yet, but work in this direction is looking promising. Andrew Yoo and his team at Washington University in St Louis, Missouri, have been studying what it takes to generate a very specific neuronal type: the striatal medium spiny neurons that are the primary cells lost in Huntington's disease. They have shown that this finely directed fate switch is indeed feasible. We must assume that something similar will prove possible for other cell types. If we can just discover each cell's particular code, then the regenerative possibilities are enormous.

It has taken more than the five years I originally anticipated, but I believe we are heading for a future where fixing broken brains may become a reality. ■

Jack Price is professor of developmental neurobiology at King's College London

Get the girl to check the numbers

In 1962, the first US astronaut to go into orbit entrusted one person with his life, the mathematician and space pioneer **Katherine Johnson**

IT WAS February 1962, and John Glenn was about to go on the journey of a lifetime. Five years before, the Soviets had shot Sputnik into space and the US was lagging badly behind. American pride and pre-eminence were riding on Glenn. And Glenn was riding on an Atlas rocket – a bomb with a seat belt, its firecracker course plotted out in exquisitely precise calculations. To make it back alive, Glenn had to put his faith in the numbers.

But Glenn didn't trust the numbers, he trusted the "girl" who devised them. He was talking about 43-year-old black woman Katherine Johnson. Almost all her colleagues were white and male. Racial segregation was widespread and no woman was considered responsible enough even to take out a loan on their own. So how did Johnson come to be as integral to US success in space as household names like Glenn and Neil Armstrong?

From an early age it was clear Johnson was clever. Born in 1918, she was in high school by age 10 and left college with degrees in French and mathematics at just 18. Even so, for many years teaching was the only work open to her. Then she heard there were jobs on offer at the Langley aeronautical lab near Newport News, Virginia, part of NASA's predecessor, the National Advisory Committee for Aeronautics (NACA). There, engineers were turning out huge amounts of data in nascent fields like jet engine and wing shape design, and faster-than-sound aircraft. "Human computers" – all women – did the mathematical hard labour. And since the second world war, jobs in the defence industry had been open to people of colour. Johnson was hired in 1953.

Virginia was a bastion of segregation. Black people attended separate schools, had to ride at the back of public buses and were banned from "whites only" restaurants; it was a crime to marry a person of a different race. Compared with the outside world, Langley was an oasis of inclusion. But the toilets, cafeteria and computing pool were still segregated.

Johnson, however, was not one to be cowed by racism. She refused to use the "colored" ladies' room, and ate lunch at her desk as she filled oversized data sheets with endless figures. And if she encountered racism, Johnson displayed a sort of wilful naiveté: "There was always a sense of, 'I dare the racism to raise its head against me! I refuse, this is beneath me, and I simply refuse to participate in it,'" says Margot Shetterly, author of *Hidden Figures* (see "The women who figured a way to space", page 42).

Johnson's talent was obvious from the start, and within just two weeks she landed a plum stint in the Flight Research Division, working alongside the aeronautical engineers. Her personality – generous, funny, confident – helped to defuse whatever scepticism the engineers might have had about her abilities.

Then, on 4 October 1957, the Soviet Union sent Sputnik into orbit. Alarm spread across the US. As the idea of a Soviet-dominated "Red sky" gripped the nation, the government took action. NACA became NASA and suddenly Langley was recast: it became the hub for space research, a key player in the effort to reach the moon and win the space race.

The flight engineers began a crash course in the physics of orbital mechanics, rocket propulsion and spacecraft re-entry, each taking a subject, learning what they could then giving lectures to their colleagues in closed-door sessions. Outside, Johnson carried on with her work, devouring every bit of information and piecing together the

Katherine Johnson fought hard to prove she was more than a mere 'computer'

action, yet relegated to the sidelines.

She longed to be included. So Johnson asked if she could join the meetings. There were no rules against allowing women, and in any case they were using her work in those sessions. To the engineers, though, women were calculators not thinkers. It just wasn't done. But Johnson was made of strong stuff, and confident in her abilities. She kept asking them to let her in, day after day, and also raised questions about the research, proving she was no mere calculator. In the end, they ran out of excuses. Her persistence paid off and Johnson

became part of the space programme. Meanwhile, the US's first astronauts moved into the next-door office to begin their training.

The Soviets had sent a satellite into orbit; the challenge now was to get an astronaut into orbit. Johnson and the engineer she partnered with, Ted Skopinski, took on the key problem of spacecraft trajectory. Using dozens of equations, they showed how to calculate the location directly beneath a spacecraft at every moment of its voyage. It was no small feat. The pair had to take coordinates in the plane of the craft's orbit – tilted relative to Earth – and translate them into familiar latitude and longitude on the spinning planet, accounting for the fact the planet bulges around its equator. It took nearly two years, yet when the paper came out in 1960, it was a major advance in mission planning, enabling astronauts to know exactly when to trigger the retrorockets to splash down on target.

But while Johnson's calculations were being programmed into new IBM computers, the Soviets struck again. Yuri Gagarin became the first human in space and the first to go into orbit. Still, the US pushed forward with its programme, and Johnson's work paid off in several successful flight tests. The next big step came in 1961, when Alan Shepard rocketed into the atmosphere, becoming the first American in space. The 15-minute suborbital flight wasn't nearly enough to catch up, but it signalled to the world that, finally, the Soviets had real competition.

Going into orbit was a much bigger undertaking and Glenn, like every astronaut, understood the risk. As the big day approached, he was worried. How could he be sure that the trajectory generated by the IBM machine would get him back home? To him, real computers were not machines, they were people – he'd seen them at Langley.

"Get the girl to check the numbers," he reportedly said. Only then would he fly. So

"She took on the key problem of calculating spacecraft trajectory"

Johnson set to work, redoing the calculations by hand. After a day and a half meticulously working through huge piles of data, she and Glenn breathed a sigh of relief: the numbers checked out.

Glenn blasted off on 20 February 1962. It was a nail-biting journey: a warning sensor meant Glenn had to skip jettisoning the rocket pack as planned. But the calculations held, and he splashed down safely in the Atlantic after his third orbit. The mission was a success. America was back in the game and Glenn became a national hero.

The celebrations were more modest for Johnson. As an unsung hero, she watched Glenn's parade around Newport News, then went back to work.

She went on to achieve much more, though. It was she who calculated the timings for the first moon landing. In later years, she worked on the space shuttle programme. Now 98, she has outlived all of NASA's first astronauts, including Glenn, who died last month. Yet only recently has her work been recognised outside of NASA. In 2015, after devoting her life to furthering our understanding of space, she received the Presidential Medal of Freedom from Barack Obama. The movie *Hidden Figures*, about Johnson and the other NASA computers, is out in the UK on 17 February.

Johnson's life has spanned a time of huge social and technological change. She was at the forefront of both. ■

By Kate Becker

The women who figured a way to space

Human calculators were much more than mere number-crunchers, finds **Manjit Kumar**

HARVARD COLLEGE OBSERVATORY, CAMBRIDGE

The Glass Universe: The hidden history of the women who took the measure of the stars by Dava Sobel, 4th Estate
Hidden Figures: The American dream and the untold story of the African-American women who helped win the space race by Margot Lee Shetterly, HarperCollins

ASSESSING the part women have played in the development of science is not easy. Historians must navigate by the documents available to them. Often, the best preserved information is financial. So inattentive writers tend to underestimate the contributions of women who achieved recognition from their peers while they were financially dependent on their families, like neurologist Cecilia Vogt or marine biologist Jeanne Villepreux-Power.

But if even intellectual celebrities get forgotten, is it any wonder that we forget the women whose contributions are hard to assess for other reasons?

Roles and titles evolve, and some jobs that appear mundane to us were not so back then. Once upon a time, "computers" were human, and often female; but these women weren't drudges. Two recent biographical histories explore the careers of the women who made modern astronomy and space science possible. Theirs were not easy lives by today's standards, but they were not without light and shade, rewards and recognition.

"One calculator was a maid. She went on to discover 10 new stars and classify more than 10,000 stars"

Dava Sobel's *The Glass Universe* starts in Harvard College Observatory, where Edward Pickering was just 30 years old when he became director in 1877. He was fond of saying that "a magnifying glass will show more in the photograph than a powerful telescope will show in the sky". It was an outlook that left a legacy of half a million photographic plates and some seminal discoveries.

Sobel describes each of these slices as "a little piece of heaven", 8 inches by 10 inches, which together constituted a universe captured on glass. Men might have taken the photographs, but it was a remarkable and talented group of "computers" who analysed and decoded the information they contained.

Pickering, a champion of the new field of photometry, wanted to establish a stellar brightness scale based on observations of stars whose brightness varies over time. Two widowed heiresses, Catherine Wolfe Bruce and Anna Palmer Draper, provided the funds. Draper in particular wanted a catalogue of stellar spectra as a tribute to her husband, an accomplished stellar photographer.

Initially, female relatives of male observatory workers were employed as computers, but soon recruits included graduates from the fledgling women's colleges. One remarkable calculator came from far humbler origins, however: Williamina Fleming was a maid hired by Pickering's wife. Fleming's natural abilities were quickly recognised. She went on to discover 10 stars, some 300 stars with variable brightness, and to classify more than 10,000 stars using a system that she devised herself. In 1899, she was appointed Harvard's curator of astronomical photographs.

Two years later, Annie Jump Cannon became the first woman allowed to operate the telescopes at the observatory, and she developed the system of stellar classification that is still used today: O, B, A, F, G, K, M.

NASA LANGLEY RESEARCH CENTER

Above: Edward Pickering's stellar calculators. Left: NASA mathematician Mary Jackson

Generations of students have learned to memorise the disorderly string of letters using the unfortunate phrase: "Oh, Be A Fine Girl, Kiss Me".

In 1912, Henrietta Swan Leavitt discovered a pattern in the brightness of a group of pulsing stars called the Cepheid variables. This was an integral part of Edwin Hubble's discovery that the Milky Way wasn't the only galaxy, and that the universe was expanding. Some members of the Royal Swedish Academy of Sciences wanted to nominate Leavitt for the 1926 Nobel prize only to discover that she had died in 1921.

A Nobel prize really should have gone to English-born Cecilia Payne in 1925, for her discovery that hydrogen was the most abundant constituent of stars. It at least earned her the first PhD in astronomy that Harvard awarded to a woman, and in 1956 she was the first female to get a full professorship at the university.

On 5 October 1957, the Soviet Union launched Sputnik, the world's first orbital satellite. By then, computers no longer simply took the measure of the stars, but were mathematicians, helping to calculate the path to the moon. Margot Lee Shetterly's father was a NASA scientist for 40 years and worked at the Langley Research Center in Virginia. He told his daughter stories of the black female computers who did calculations for engineers while segregated from their white colleagues. Young Shetterly "knew so many African Americans working in science, math and engineering that I thought that's just what black folks did".

Hidden Figures tells their story. It's an engaging read, and a film adaptation is already on general release in the US. Shetterly weaves together the personal and professional stories of a group of extraordinary women into an account of how they overcame race and gender barriers, while helping to win the space race.

"Human computers no longer measured stars, but helped calculate the path to the moon"

"What black folks did"

"Mississippiitis" looms large – a term coined by *The Chicago Defender* newspaper at the time to capture the "disease of segregation, violence and oppression that plagued America like a chronic bout of consumption" and which was, for some, the reason the country had fallen behind the Soviets.

Shetterly celebrates the skills, achievements and tenacity of women like Dorothy Vaughan, Katherine Johnson and Mary Jackson as they helped launch rockets and humans into space.

In 1953, Vaughan was at the National Advisory Committee for Aeronautics, the precursor of NASA, heading a department of black female computers. They were joined by Katherine Johnson (profiled on page 40), the woman who helped put John Glenn into orbit and mapped the trajectory for Apollo 11's moon landing, among other firsts.

There's an easy moral here: that Neil Armstrong's "giant leap for mankind" will only loom larger in our imaginations once we appreciate all the people – men and women – who got him there. ■

Manjit Kumar is science writer based in London

The solutions to our fiendish brain-teasers

From 17/24/31 December issue, p 86

Puzzle 1: Which match should you have moved? The fourth from the left to make the equation "the square root of 1 is equal to 1".

Puzzle 2: From the dialogue, we know that Reese doesn't have the salt because he responds to the person who does, and he can't have the relish because of his name. Reese must have the pepper, Sid the relish and Phil the salt. We are told the man doesn't have the relish, and the dialogue shows the man doesn't have the salt either. The man must have the pepper, so Reese is the man.

Puzzle 3: With 5 couples present, a person can shake hands with a maximum of 8 people they don't know. The 9 different answers Noel received must thus have been 0, 1, 2, 3, 4, 5, 6, 7 and 8. The person who said 8 shook hands with everyone bar their spouse. This means everyone shook at least 1 hand, except for this person's spouse. So the person who shook 8 hands must be in a couple with the person who shook 0 hands. Continuing on, the person who shook 7 hands must be the spouse of the person who shook 1 hand, and the same for 6 and 2, and 5 and 3. The remaining person, who shook 4 hands, is Holly because she is the only one not in a couple with someone who responded to Noel's question.

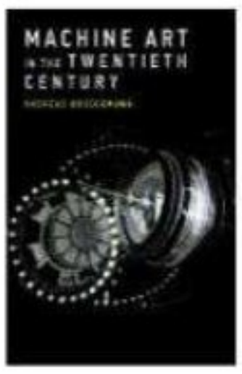
Puzzle 4: No answer required. We hope you enjoyed a perfect egg!

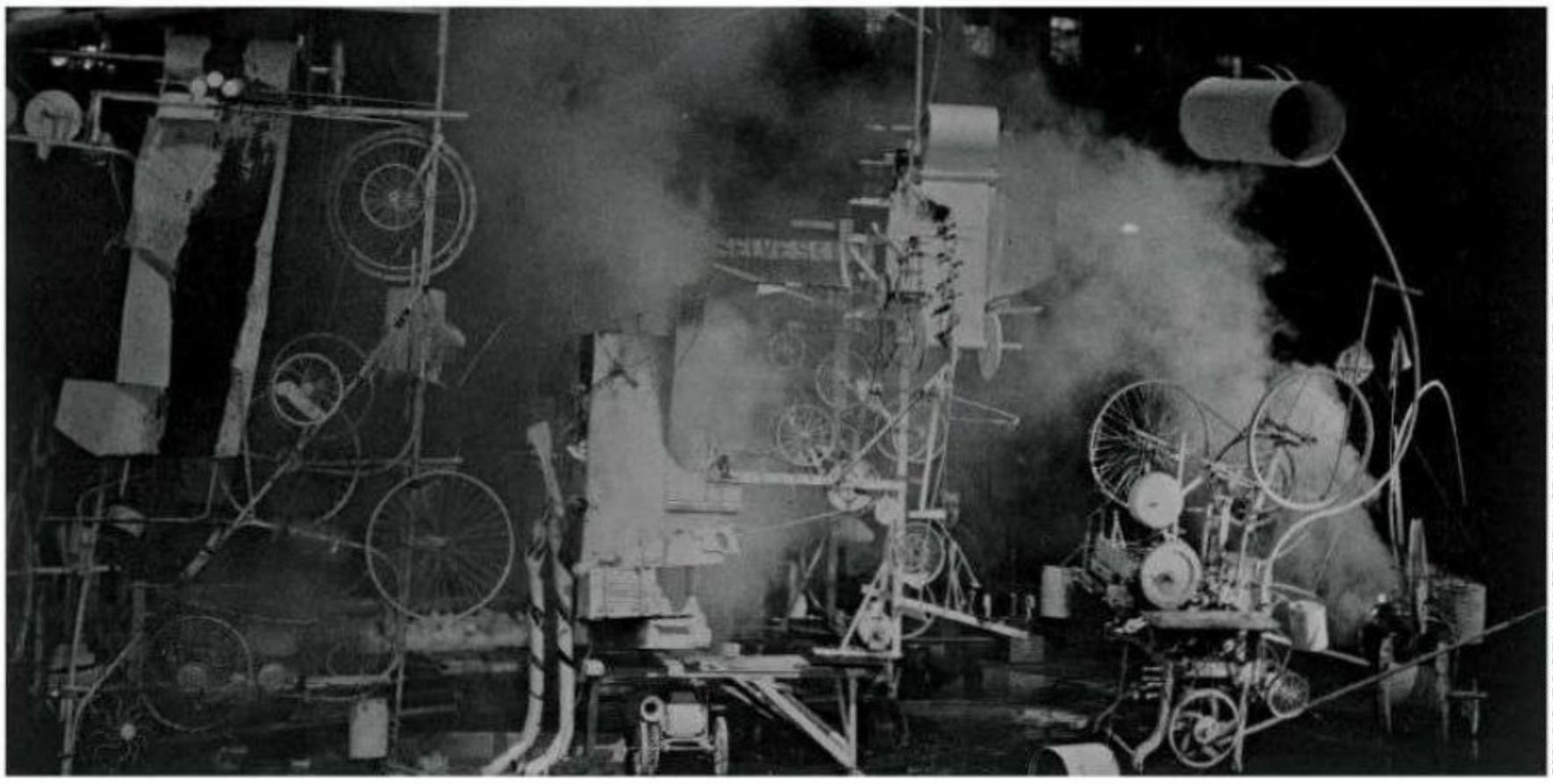
Puzzle 5: The probability that a search is unsuccessful is 0.35, calculated by 1 − 0.65 = 0.35. The probability that the wrapping paper is in the main room and you failed to locate it is 0.7 × 0.35 = 0.245. The wrapping paper is still more likely to be in the main room than in either of the other rooms. Look again! ■

Dreams and nightmares

What makes humanity in a world of machines, asks **Jonathon Keats**

Machine Art in the Twentieth Century
by Andreas Broeckmann, MIT Press





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Up in smoke: Jean Tinguely's *Homage to New York*

IN PREPARATION for his 1960 debut at New York's Museum of Modern Art, Jean Tinguely salvaged a pianola and a go-kart. He also recovered old electric motors, and hundreds of wheels from bicycles and baby carriages, which he rigged into a giant machine. This had only one function: self-annihilation. He set the wheels in motion in the courtyard of the museum. As the mechanism started to break apart and the pianola went up in flames, Tinguely's *Homage to New York* terrified spectators and the fire department hastily shut it down.

Today, *Homage* is one of the most celebrated works of 20th-century machine art, and Tinguely is a central character in the tumultuous relationship of art and technology. He is also key to Andreas Broeckmann's new book, *Machine Art in the Twentieth Century*. Tinguely's suicidal apparatus, writes Broeckmann, "sought to pathologize the mechanical". And as machines infiltrated our lives, so art became essential to working out our techno dreams and nightmares.

According to Broeckmann, art started to confront machinery systematically only in the second decade of the 20th century, long after the industrial revolution had done its work. Yet once artists took it up, they did so with great vigour and variety. First were the Italian Futurists, driven by F. T. Marinetti's 1909 manifesto, declaring fast cars more beautiful than the world famous sculpture of Nike, the *Winged Victory of Samothrace*, and calling for a new art built on "the beauty of speed".

Just a few years later in Berlin, the Dadaists reacted to the mechanised cruelty of the first world war (which the bellicose Futurists had enthusiastically endorsed) by depicting absurdist mash-ups of functionless gears.

"Art only confronted machinery long after the industrial revolution had done its work"

And in the new Soviet Union, the Constructivists were designing a techno-utopia, casting themselves as hybrid artist-engineers.

These three visions recur and intermix across Broeckmann's book, taking different guises in the hands of different artists at different stages of technology. Lengthy description, careful interpretation and good contextualisation ensure it is broadly accessible – provided readers can endure his pedantic style and jargon. The result is a strong case for the importance of machine art and a solid foundation for understanding our relationship with technology through art.

Technophilia remains a notable strain of artistic engagement with machinery, although it has matured since the Futurists tried to topple Nike. One of the most persistent enthusiasts is Stelarc, an artist who has spent decades augmenting his body. In the 1980s, he hung his naked body from a winch, with hooks piercing his skin, using a handheld remote to manoeuvre in unnatural ways. His experiments have grown more sophisticated as technology advances and he extends his exploration of human identity. But even his later bionic body corset possesses mad-scientist ropiness.

The awkwardness of this machinery is essential, positioning Stelarc's work as philosophical propositions rather than Silicon Valley products. As Broeckmann says, his art asks if humanness has a particular site in the body.

Other artists have advanced a more nuanced version of the dystopian Dadaist vision. One of the most compelling in the book is Wim Delvoye. His *Cloaca* mimics digestion by pumping food through glass vats, processing it with chemicals and microbes to produce pungent "faeces". For Delvoye, *Cloaca* is "a human being without a soul", provoking the question of what remains of us as technologies take our place, while also holding on to the possibility that there is more to us than we can reduce to machinery.

Like all worthy machine art, and unlike ordinary machines, *Cloaca* is a mechanism for introspection. The excrement is merely a byproduct. ■

Jonathon Keats is the author of *You Belong to the Universe: Buckminster Fuller and the future* (Oxford University Press)

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Meet up — and make science happen!

Science is a process best shared. Securing a travel grant can help open opportunities for collaboration and careers, writes Rolly Simpson of the Burroughs Wellcome Fund.

The photo that Frank Beier tweeted said it all: a happy, visiting colleague at the lab bench, flashing two thumbs up (properly gloved) and a cheeky grin.

"It's great to welcome @CampbellRolian from @McCaigInstitute for a collaborative visit to the lab. Thanks @BWFUND for funding this exchange!"

As a junior faculty member at the University of Calgary and the McCaig Institute for Bone and Joint Health in Canada, Campbell Rolian studies the evolution of skeletal structures. In particular, how do limb bones grow and develop, and how do these mechanisms influence skeletal variation, evolution, and diseases in vertebrates?

Naturally, Rolian is keen to stay current on methods for growing bone tissue, and for some years, he had been looking for a chance to work with Frank Beier at Western University. Beier investigates the molecular and cellular mechanisms controlling bone growth, and his lab specializes in culturing embryonic bones.

In other words, Beier brews bones, and Rolian wanted a taste of his technique. However, Beier's lab was located 1,600 miles (2,600 km) east of Calgary. Fortunately, Rolian had applied for a Collaborative Research Travel Grant (CRTG) from the Burroughs Wellcome Fund. Using the grant for travel and supplies, Rolian was able to spend 10 days in London, Ontario, training alongside the Beier Lab team, culturing embryonic bone in petri dishes, and exchanging cross-disciplinary perspectives with students and postdocs.

"It's one thing to follow a written protocol, but it's an entirely different thing to be able to shadow and observe someone doing it, and then repeat it in front of them," says Rolian. "Being there makes it easier to learn quickly and efficiently, and to troubleshoot with the experts! It means the feedback is instantaneous too, rather than stopping everything to write an email on some minor question."

"There are many benefits to face-to-face contact that cannot be recapitulated by other means—the chance to answer questions in real-time, look at things from different angles, and d o procedures with your own hands while an experienced experimentor looks on," says Beier. "In the bigger picture, Campbell and I arrived at our common interest in bone growth from very different starting points. Being able to discuss these different perspectives proved eye-opening—for myself and for my trainees."

In 2016, the Burroughs Wellcome Fund awarded nearly 50 CRTG proposals. The grant enables investigators in U.S. and Canada to bridge wide distances (Edinburgh, Joensuu, Karachi, Taipei, Dar es Salaam, to name a few), and more importantly, widely different disciplines (parasitology, computational biology, immunology, and biophysics, among others)—and affords them the flexibility and needed time to exchange ideas and inspire new research directions.

"I think the most fun was to see Frank's lab in action. He has a fantastic and diverse group of very bright scientists, and it gives me, as a junior investigator, something to aspire to," says Rolian. "Another major benefit of the CRTG is that we can generate preliminary data to use in future grant applications, and can demonstrate our expertise to carry out the proposed procedures. Plus, armed with the new techniques, I can be on the same wavelength with Frank in terms of proposed projects, because now I can speak from experience when I propose to do a specific set of experiments."

"I'm already looking forward to the next visit!" Rolian says.

The best brainstorms and innovations in biomedical research happen when researchers can collaborate and share ideas in person. Finding and securing a grant that allows for exploratory, enriching visits with colleagues at distant institutions can make a world of difference. So meet up, and make science happen!

—Rolly Simpson

Rolly Simpson is a Senior Program Officer with the Burroughs Wellcome Fund.

Researchers at U.S. and Canadian degree-granting institutions are invited to apply for the Collaborative Research Travel Grant, and receive up to $15,000 for domestic or international travel for one year. Proposals are due February 1st, 2017. Go visit a colleague—and grow your skills, your collaboration, and your career.

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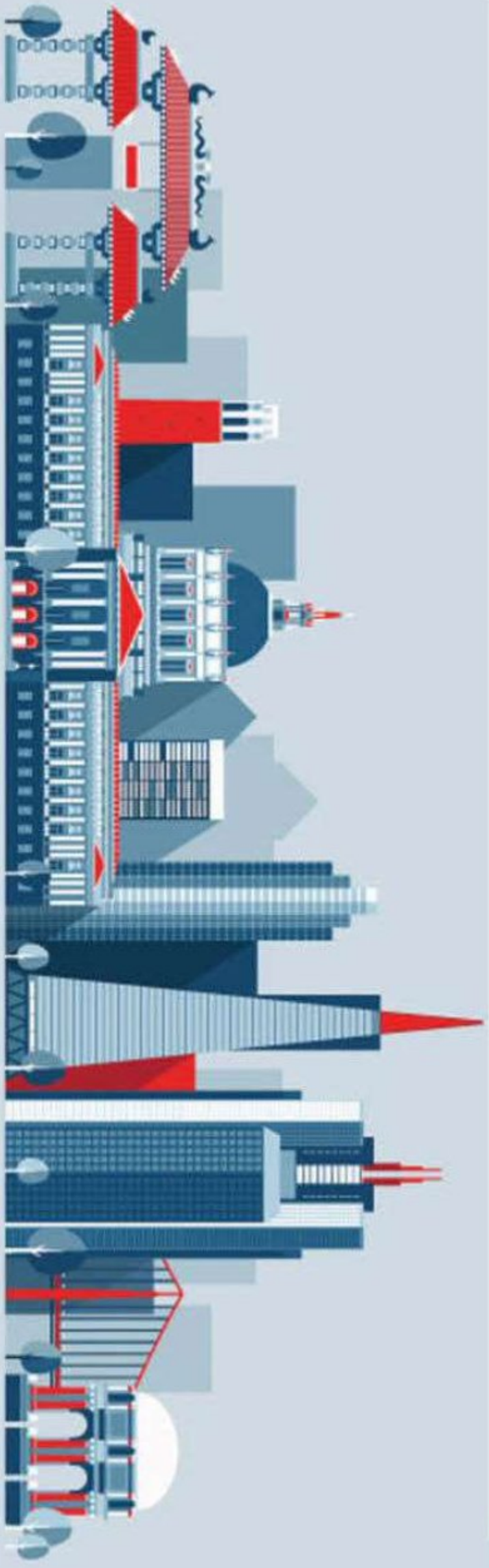

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EDITOR'S PICK

People must undo local ties before changing

From David Werdegar, Naperville, Illinois, US

Dan Jones omits a crucial precondition for people to be able to acknowledge fact-based evidence and reverse their beliefs on controversial subjects (3 December 2016, p 28). So much depends on the degree to which a person has to undo commitments made to other people. Someone who privately believes in unrestricted gun ownership but is not a member of a local gun club or the National Rifle Association, for example, may have less difficulty considering gun control than would the head of an NRA chapter. Change in individuals requires change in the groups they belong to.

A community may react to crop failures due to seeds spoiling in warm, moist soils, but resist climate change initiatives in general. Children's deaths in a measles epidemic may increase immunisation rates faster than people being told that reports of vaccine harm were a sham. Unless people's resistance and denial result in severe, local consequences that allow them to change tack without losing face with their neighbours, significant fallacy reversals are unlikely.

Whose job is it to burst the filter bubble?

From Malcolm Shute, La Tour d'Aigues, France

Sally Adee seems to suggest that responsibility for making sure people are not presented with a biased view of the news and current affairs via the internet rests with the media user (26 November 2016, p 24).

Surely this is not sufficient. Not all readers will see the need to click on any "widen perspective" button that may be provided.

The approaches described suggest to me that no social media or search-engine owners are planning to do anything about the problem. Or not, perhaps, until the first murder cases resulting from their inaction start appearing in the courts. If users are living their lives in biased and conspiracy-believing worlds of make-believe, it cannot be long before we see misguided lynch mobs roaming the streets.

'Criminality' is far from being a physical fact

From Jo Spencely, Edinburgh, UK

You report Xiaolin Wu and Xi Zhang having trained software so that it "correctly identified criminals 90 per cent of the time" (10 December 2016, p 20). But which "criminals"?

Did it pick out lawbreakers such as homosexuals, bankrupts and drinkers of alcohol? Critics of the ruling party? Strike organisers? Adulterers? Apostates?

All these activities are or have been treated as crimes somewhere in the world. Researchers need reminding that criminality is a social construct, and not a biological fact.

"Could the reason be that most mothers are right-handed and need that hand free?"

Jessie M. H. offers a simpler hypothesis than right-brain specialisation for mothers mostly holding babies on the left (14 January, p 10)

Please desist from the insults, doom and gloom

From Paul Marshall, Great Yeldham, Essex, UK
Your Leader articles seem to frequently insult and demean those (indeed the majority) in the UK who voted for Brexit. For most of us, 600 years of evolving parliamentary democracy carries rather more weight than what may be perceived as a failing utopian dream.

We are not about to withdraw from the scientific community in Europe: funding has been declared a government priority and the Confederation of British Industry has announced an expected bonanza in science and technology jobs. So please desist from the insults, and doom and gloom, and concentrate on the science – or some of us may look elsewhere for our enlightenment.

The editor writes:
■ We mean no offence to those who backed Brexit, for which there are principled arguments (4 June 2016, p 18). We do not, however, respect those who sought to win by peddling falsehoods. As to the outlook for British science, we have welcomed recent good news, but remain to be convinced this does much for its long-term security (26 November 2016, p 5).

A volcanic impact on the English countryside

From John Davnall, Manchester, UK
David Hoey asks about possible effects of the 1783/84 eruptions in Iceland on English agriculture (Letters, 17/24/31 December 2016). Gilbert White's 1789 book *The Natural History of Selborne* describes atmospheric conditions in the summer of 1783 that match those associated with the 1815 explosion of Tambora in the East Indies.

England saw a rise in wheat prices in 1783, which persisted for the next two years: from this we can infer that harvests were thin. The Central England Temperature record shows below-average temperatures in 1783 and 1784 (as it does in 1815).

A pair of my forebears died at that time. In their parish there were more burials in the summer than in the years to either side. It is tempting to suppose that air quality was involved.

We should remember, though, that industrialisation was already drawing labour from agriculture, and that the introduction of the "Speenhamland system" of poor relief by wage top-up from 1795 had unintentionally adverse effects on rural labourers.

The Honourable Robot for Eatanswill will stand

From Brian Horton, West Launceston, Tasmania, Australia
Zoltan Istvan discusses giving robots the vote when they are as intelligent as the average human (17/24/31 December 2016, p 18). I'm all in favour of this, since they will be completely logical (like me). But what I would really like is a robot to replace politicians.

The results of an innate sense of fairness

From Natasha Lee, Sydney, Australia
I read with interest Michael Norton's comments on earnings differentials (10 December 2016, p 18). They remind me of studies that find a sense of fairness in primates (20 September 2003, ›

p 19). Could this be behind the outrage over chief executives' pay? Often politicians and supporters of high executive salaries dismiss such outrage as "the politics of envy".

I believe the outrage is more likely to be driven by the sense that in Western economies most executives are white men, and those expressing outrage can never join this elite, regardless of skills or ability.

Many believe the idea of a meritocracy is a lie, since they face "glass ceilings" because of their gender, race or class. Recently, executive salaries have reached levels that are considered obscene. Was this a catalyst for anti-establishment attitudes in the general population?

Our bugs probably do not outnumber us

From Sylvie Yannello, Long Island City, New York, US

Daniel Cossins repeats the widely circulated factoid that our bodies contain "perhaps 10 times more" bacterial cells than human cells (10 December 2016, p 31). This has been rebutted by the biologists Ron Sender, Shai Fuchs and Ron Milo, whose study you mentioned at the beginning of last year (16 January 2016, p 14).

Sender and colleagues write that the myth of a 10:1 bacterial-to-human cell ratio is based on a single "back-of-the-envelope estimate" by the biochemist Thomas Luckey in his 1972 paper "Introduction to intestinal microecology".

Finding meteorites in your gutters is easy

From John Rowland, Derby, UK

You report the "first time" that cosmic dust has been found in urban dirt (17/24/31 December 2016, p 12). Iron micrometeorites are in fact very common and easy to find wherever rain is frequent and guttering to catch it is fitted to buildings.

Iron space dust that is fine enough to escape incineration as "shooting stars" when entering Earth's atmosphere drifts down continuously. To collect these small iron spheres, scrape several handfuls of mud from a convenient roof gutter, preferably a plastic one, add to a bucket of water and stir.

Fish for meteorites with a strong magnet wrapped in a plastic bag. Remove the magnet, carefully rinse the bag into a glass dish and look for fine, dark grey dust. Dragging the magnet underneath will concentrate the dust. A good magnifier will show tiny spheres, some of them up to 0.2 millimetres in diameter.

Gender effects on sickness seen before

From John Davies, Lancaster, UK

Gian Volpicelli reports that while using an Oculus Rift virtual reality headset, 78 per cent of women but only a third of men report motion sickness (17/24/31 December 2016, p 21). The researchers refer to previous reports of this effect as "anecdotal". Perhaps they are not aware of a related gender difference in the incidence of post-operative nausea (PON). Anaesthetist Gavin Kenny found as long ago as 1994 that women were three times more likely to have PON than men.

Other risk factors for PON include a previous history of motion sickness, use of opioid drugs and – to the chagrin of all doctors – being a non-smoker.

As patients tend to lie still while they recover, the suggestion that the difference is due to women having greater body sway seems unlikely. Anaesthetists don't have much of a theory either. As usual, more research is needed.

Monkeys bite their tongues for the quiet life

From Elsa Beckett, London, UK

You ask why monkeys don't talk, given their vocal apparatus (17/24/31 December 2016, p 15).

When I was a child in what was then Rhodesia, I heard people say that monkeys speak perfectly well among themselves but never let humans hear them because then they would be made to work.

TOM GAULD

For the record

- Brighton is the UK town that had 16 urban foxes per square kilometre in 2013-2015 (7 January, p 6).
- Giving a woman a steroid before 9 weeks of pregnancy can alleviate some of the symptoms of congenital adrenal hyperplasia, such as genital ambiguity (7 January, p 8).
- Periodic error: Russian scientist Dmitri Mendeleev produced his table of the elements in 1869 (Quiz, 17/24/31 December 2016).
- Flippin' 'eck: the north and south poles of Earth's magnetic field swap places every few hundred thousand years (14 July 2012, p 14).

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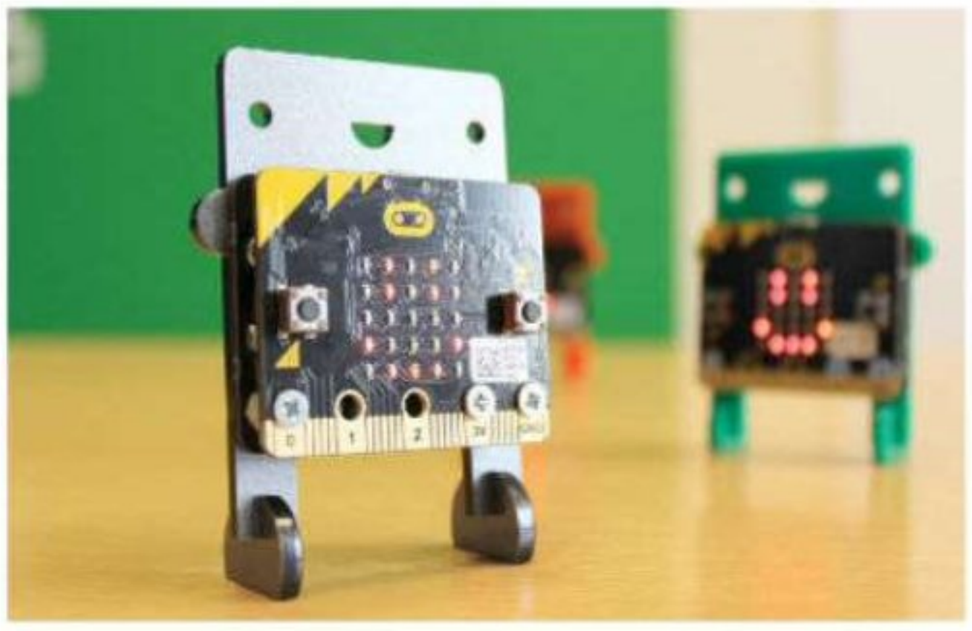

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World of invention

EVERY child has an inner inventor. I remember when I was a kid, getting excited over all the little build-your-own kits I was able to get my hands on. Technology opens up possibilities and can help us achieve near-miraculous things, but it can also be complicated. In fact, it is so complicated these days that it can sometimes seem completely out of reach.

Launched last year, the BBC micro:bit, a pocket-sized, programmable computer, was designed to change this. The aim was to help every child unlock their creativity with technology, and the device was given free to a million 11-year-olds across the UK, introducing them to the world of invention. Already, a number of exciting micro:bit projects have been brought to life, from acceleration measurement in rocket cars to helping people with autism recognise other people's emotional states.

Following the success of the BBC project, the Micro:bit Educational Foundation was born. It's a not-for-profit organisation that will support the global roll-out of the micro:bit. As the CEO of the Foundation I now have the chance to work with teachers, governments and organisations around the world to help spread digital literacy, and make an impact on people's lives and futures.

A country's most valuable source of innovation is its youth. Helping young people experience the self-fulfilment of digital creativity is vital for motivating the next generation of inventors. Our research has already confirmed that the micro:bit has encouraged children to consider pursuing science, technology, engineering and maths in the future. With the support of our partners, including the BBC and technology companies ARM, Microsoft and Samsung, we will continue to inspire them.

The micro:bit is being spread around the world as a grassroots effort – and you can get involved by helping a child, a local school or a coding club get started with it.

Zach Shelby, CEO Micro:bit Educational Foundation

For more information on how you can get involved visit **microbit.org**

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PAUL MCDEVITT

SCOTLAND is well known for its experimental chip-shop cuisine, which has pushed the limits of which food items can be battered and dropped into hot oil, from haggis to Mars bars. Now Murdo Macdonal brings news that the network of Food Researchers in Edinburgh goes by the apposite acronym "FRIED".

DURING the festive season, Arthur Coker spotted a model kit for sale that offered the chance to "build your own skeleton, then add flesh and skin," which, it added, was "Four dimensional".

Arthur says he wants to buy one "and watch it age", though Feedback wonders if all hobby kits are four dimensional toys, unless you are an impossibly fast builder.

FEEDBACK heard that the online IKEA repository containing all the assembly instruction booklets for their furniture is itself "under construction" (19 November 2016).

Martin McGovern writes to say that a short while ago, he had reason to visit the website of United Biscuits – "from where one can visit another page containing their cookie policy," says Martin. "I don't normally click on those links, but I couldn't help thinking that they ought to know better than most."

ON THE subject of last words (19 November 2016), Andrew Sanderson writes: "As a GP, I spent much time telling my patients and my children to 'leave it alone, it will get better'. My daughter has promised to engrave my tombstone with 'He left it alone and it didn't get better'."

CROSSING the median when driving could be dicey in more ways than one, finds Alan Smithee. His membership with the AAA roadside assistance service warns him that "a Member who requests or uses an excessive amount of Service; that is, uses Services over a sustained period that are greater than the average Member uses, may be subject to membership downgrades at renewal or the non-renewal of the membership."

Feedback thinks that this policy ought to gradually reduce the average number of call-outs over time. Certainly that's one way to keep customers moving.

ANDREW DOBLE finds the future isn't all it turned out to be, pondering why "self-winding watches have been around for 240 years, yet my Fitbit has to be recharged regularly".

Feedback assumed it was a design feature – walking around the house plugging in all our health tracking gadgets is the only exercise we get.

OUR inbox continues to be peppered by readers unpicking the mystery of whether "Himalayan sea salt" deserves its name. Allen Reynolds notes that if it is named after the location of its source, the Khewra mine, the salt is produced "310 kilometres from the Himalayas, but only 260 km from Lahore. Doesn't this make it Lahore sea salt?"

But if it is based on where the salt was laid down 800 million years ago, in what was then an evaporating sea, says Allen, two thirds of its name are justified. "But there were no Himalayas back then, as the mountain range is only some 55 million years old."

WITH a warming world on his mind, Don Wycherley is pleased to discover that department store Marks & Spencer sells what it calls "climate control" trousers. "One can only hope that these will achieve a significant reduction in the emission of greenhouse gases," says Don.

SPARE a thought for Brits struggling to keep their homes warm this winter, thanks to puzzling restrictions on buying coal. Terry Jeffries discovers a UK government page listing regulations on solid fuel, which declare it can only be sold in quantities of 25 kilograms, 50 kg and multiples of 50 kg.

"So, if I want to buy 125 kg of loose coal," says Terry, "I'll have to order 100 kg and 25 kg and ask for it to be put in the same bag".

Terry notes that the same page also tells him what units whisky can be sold in – which might be useful for keeping warm until the coal merchant arrives.

MEANWHILE, Faith Anstey discovers her local coal merchant offering "Homefire Ovals" for sale, which are described as "oval-shaped ovoids".

The alternative to these oval-shaped ovoids, says Faith, are described with the words "super", "new" and "premium", and are 40 per cent cheaper. How do they manage to sell any Homefire Ovals at all? wonders Faith.

REX WAYGOOD finds himself in the dark when it comes to changing his lightbulbs. He purchased a "star classic" LED bulb that boasts an energy rating of "10 kWh/1000h".

"I quickly worked out that was 10 watts," says Rex, "but could they have used a more obtuse power rating?" A closer look at the packaging revealed the bulb was identified as drawing 9.5 W. "Where is the extra 0.5 W coming from or going?" asks Rex. Perhaps it's the energy you expend trying to understand 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.

Ian Henderson is told that his trial period for AVG anti-virus software has been extended by 2147483647 days, "or the best part of 6 million years". Time enough to make a decision?

Bolted on

Is the exact spot where a bolt of lightning will strike the earth pretty much predetermined at the moment it leaves a cloud? Or does it continuously change direction on the way down?

It seems there's some disagreement between electrical and meteorological experts – Ed

■ The point of a lightning strike is not predetermined. When the electric field in a cloud creates ionisation in the air, a streamer discharge occurs. Usually negatively charged, it spreads out following a random path probably determined by local moisture, dust and cosmic ray ionisation tracks. Indeed, it has been suggested that cosmic rays kick-start the whole discharge process by creating an ionised path in the cloud.

As this leader streamer or spark nears the ground, the electric field becomes so intense that positive streamers develop from elevated structures, such as trees, buildings and power lines. When the downward streamer meets one of the upward streamers, a full-blown lightning discharge occurs down the pre-ionised path. This is what we see – we do not see the streamers.

Ron Barnes
Electrical power engineer
King's Lynn, Norfolk, UK

■ The strike point of a bolt of lightning is pretty well determined the moment that the discharge begins from the cloud.

For lightning to form, there needs to be a net negative charge at the base of a cloud (normally a cumulonimbus) and a positive charge at the ground. Initially, negative charge builds up at the cloud base, until an electrical field of at least 3 million volts per metre develops.

Electrical discharge proceeds along a path of about 50 metres, pauses for about 50 millionths of a second, then proceeds over the next 50-metre segment, and so on. This forms what is known as the step (or stepped) leader.

At the same time, a positive charge is building from the ground – or the tallest object near the surface, which may be a tree, building, steeple or even a person.

The positive charge rises to meet the descending step leader, and the connection between the two forms the lightning path. Current then flows back into the cloud. This is the "dart leader" and is what we see; the semblance of lightning discharging from cloud to ground all in one go is an optical illusion. So, the point where the positive stroke starts to rise from the surface determines where the strike will form.

Peter Burt
Biometeorologist
Natural Resources Institute, Chatham, Kent, UK

■ The spot where lightning will strike is determined in the last 100 or 200 metres of its path by local conditions.

A lightning discharge is set up by the friction between air, ice crystals and water droplets in a cloud. The charge is usually positive at the base of the cloud and negative at the top.

The non-uniform distribution of charge results in voltage gradients in parts of the cloud. When these reach a sufficient level, the air is ionised as electrons are torn off their respective atoms, forming a conductive plasma or arc. These arcs are not very long – usually about 50 metres.

The charge will then move down the arc path, creating another high voltage gradient as it goes. This may cause further ionisation, and so the process continues.

"The semblance of lightning discharging from cloud to ground all in one go is an optical illusion"

The direction taken by the next ionisation channel is randomly determined by prevailing conditions, giving lightning discharges their typical zigzag pattern. The leader, as the channel is called, can head upwards or downwards. If it goes up, you get a cloud-to-cloud strike that lights up the cloud from inside.

If it heads down and approaches the surface, it induces the opposite charge there. Voltage gradients between the end of the leader and Earth become very high, with the air becoming ionised at both the leader end and the surface. As a result, a number of ionised paths will form at the surface and extend upwards towards the leader end. (When this phenomenon occurred on wooden sailing ships, it was called St Elmo's fire.)

When a path from the surface connects with the descending leader, the charge built up in the cloud can drain. The discharge currents can be very high, with values of 250,000 amperes recorded.

The circuit consists of the cloud base, the discharge channel and Earth, each with its own electrical resistance. The upshot of this is that the energy isn't completely absorbed at each end, and so the discharge is reflected several times, resulting in the pulsing light and strobe effects we associate with lightning.

We can encourage the lightning channels to form at desired places on the surface, thus avoiding damage, by introducing conducting rods that are connected to Earth.

As an aside, the notion that lightning does not strike twice in the same place simply isn't true.

Alex Hromas
Hunters Hill, New South Wales, Australia

This week's question

SILVER LININGS?
Should we expect clouds to look different as global warming proceeds?
John Smith
Sudbury, Suffolk, UK

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