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The beginning of the end

We've missed many chances to limit warming. This may be our last

IT WAS always likely to come to this. Despite decades of ever-starker warnings, and years of increasingly obvious changes to the climate, we still haven't done nearly enough. Now, according to the latest report from the Intergovernmental Panel on Climate Change (IPCC) – the UN's advisory body on the science of global warming – we are rapidly running out of time. Limiting warming to a manageable (but still dangerous) 1.5°C is possible, strictly speaking, but it would require "rapid, far reaching and unprecedented changes in all aspects of society" by 2030 (see page 6). That would mean starting not some time in the future, but right now.

Will humanity do what's necessary? For individuals, that means making sacrifices and sticking to them, forever. For politicians, that means an end to the indulgence of the fossil fuel industry; investing in renewable energy, and carbon capture and storage; radically transforming transport; halting deforestation; and dropping the remorseless pursuit of economic growth above everything else.

Will all of this happen? Your response is probably "not likely".

If we don't act, though, the consequences are grave and they are going to hit us within the lifetime of our grandchildren. As the IPCC says, even if everyone sticks to the Paris Agreement, we are currently on course to warm the planet by 3°C by the year 2100. That would mean a decisive end to the balmy and benign Holocene climate that allowed our civilisation to flourish, and the start of something much less hospitable. Heatwaves, flooding, wildfires, drought and famine will become much more common "in every inhabited continent" – which is why most of us try not to think about it too much.

"We still have time for a rescue, but it will be the largest project humanity has ever undertaken"

If anything, denial is deepening. The populist revolt is hostile to climate action and its leaders have managed to tar environmentalists as just another wing of the liberal elite. Populism thrives by offering simplistic solutions to complex problems – the exact opposite of what the world needs right now (see page 4).

The natural reaction to the IPCC report and wider developments may thus be despair. But that guarantees only one outcome: defeat. As the report makes clear, we still have time to pull off a rescue. It will arguably be the largest project that humanity has ever undertaken – comparable to the two world wars, the Apollo programme, the cold war, the abolition of slavery, the Manhattan project, the building of the railways and the rollout of sanitation and electrification, all in one. In other words, it will require us to strain every muscle of human ingenuity in the hope of a better future, if not for ourselves then at least for our descendants.

Is it possible? Over the coming weeks and months, we will be reporting on the ways in which we might transform society to avert the crisis.

The history of humanity is one of stupidity, denial and dawdling followed by heroic rearguard action to prevail against all odds. The climate crisis is close to that inflection point. Does our generation have the gumption? It is time to find out. ■

NASA

Hubble trouble

ONE of our most important windows on the universe, the Hubble Space Telescope, has been taken offline after two of its gyroscopes failed.

"Very stressful weekend," Hubble's deputy mission scientist, Rachel Osten, wrote on Twitter. "Right now HST is in safe mode while we figure out what to do."

Hubble has six gyroscopes, which measure the rate of motion as it moves, ensuring the telescope stays pointing in the right direction. Three are needed for it to work most efficiently, but two had previously failed and two went down over the weekend, leaving only two now working.

Hubble can still operate with one or two gyroscopes, but its view of the sky is restricted. The mission team hopes that one of the gyroscopes might yet be brought back online.

"Hubble's instruments still are fully operational and are expected to produce excellent science for years to come," said NASA in a statement.

Hubble has been observing the sky since 1990. All six gyroscopes were replaced when it was last serviced in 2009 by a crew of astronauts flying on the space shuttle. The space shuttle retired in 2011, and it is not currently possible to send astronauts for another repair mission.

In 2016, NASA announced that the telescope would continue operating until June 2021, by which time its successor, the James Webb Space Telescope, is due to be working, although that project has been repeatedly put back.

Prize for pricing climate change

THE 2018 Nobel economics prize has gone to William Nordhaus and Paul Romer for integrating climate change and technological innovation into macroeconomic analysis.

Nordhaus, at Yale University, created the first model describing the interplay between the economy and the climate in the 1990s. His work is now used to study the consequences of climate policies and has been very influential in guiding thought about how the world should tackle climate change, with a key recommendation that governments, corporations and households should have to pay a price on carbon emissions.

Romer, at New York University, is known for demonstrating how economic forces influence the willingness of firms to produce new ideas and innovations, and how knowledge can drive economic growth. In 1990, while mainstream economists were expecting growth to taper off, Romer overturned this idea by emphasising humanity's limitless capacity for invention.

Brazil may exit Paris climate deal

IT IS not a move in the right direction. The first round of Brazil's presidential election has been won by a far-right candidate who wants to withdraw from the Paris climate agreement. This comes just as a major climate report has highlighted how we aren't doing nearly enough to meet the targets of the deal (see page 6).

Jair Bolsonaro (pictured) will face a left-wing Workers' Party candidate in the second round on 28 October after he failed to get 50 per cent of the total votes – the requirement to win outright in the first round.

As a large developing country and home of the Amazon rainforest, Brazil's actions really matter when it comes to limiting further climate change. At one point, the country had succeeded in greatly slowing deforestation, but in recent years the rate of loss has soared.

The Amazon rainforest is being cut down to make way for cattle ranches and soya farms. High prices for soya, as well as reduced funding for forest protection, are behind the change.

MAURO PIMENTEL/AFP/GETTY

Google's social network is closing

GOOGLE is shutting down its social network, Google+, for non-business users, following the disclosure of a flaw found in March that exposed personal information of up to 500,000 people.

The news came in a blog post on Monday, which was Google's first public description of the privacy bug. Citing anonymous sources, *The Wall Street Journal* said Google deliberately avoided disclosing the problem at the time, in part to avoid drawing scrutiny.

The flaw could have allowed 438 external apps to scoop up user names, email addresses, occupations, gender and age without authorisation. The company says it found no evidence that any of the affected personal information was misused. It says that is one reason it delayed disclosing the problem.

Google+ was supposed to be a challenger to Facebook's social network, but it flopped and quickly turned into a digital ghost town, prompting Google to start de-emphasising it several years ago.

First 'hive mind' game of Tetris

Three connected brains solve one problem in a world first. By **Chelsea Whyte**

JACK GUEZ/AFP/GETTY IMAGES

Chelsea Whyte

USING only their thoughts to communicate, three people wearing brain-reading caps worked together to play *Tetris*. This is the first instance of more than two people collaborating through brain-to-brain communication.

"Our experiment can be regarded as the first proof-of-concept demonstration that multiple human brains can consciously work together to solve a task that none of the brains individually could," says Rajesh Rao at the University of Washington in Seattle.

Using this BrainNet interface, three people can combine minds to play a slow version of *Tetris*. The first two send information about the state of the game to the third player, who decides which moves to make.

The two senders wear electroencephalography (EEG) caps to record the brain signals produced by their thoughts, while the receiver wears a transcranial magnetic stimulation (TMS) cap that delivers the information to their brain.

The senders can see the entire play area, and so have to tell the receiver whether or not to rotate the target block. The receiver only sees this current block, not the state of play, so must rely on information from the senders.

They communicate with the receiver by focusing on one of two flashing LED lights that sit next to the words YES or NO on either side of a computer screen. This choice can be seen in the EEG data, in signals from the visual cortex.

To pass on this information, the receiver's occipital lobe – the brain's visual processing centre – is stimulated magnetically by the TMS cap when the senders think "yes", causing the receiver to see a flash of light.

The senders have 15 seconds to send their decision, and the two decisions are received 8 seconds apart. "The real *Tetris* game would be too fast for the current version of BrainNet," says Rao.

The team also tested whether the receiver could judge if the guidance was accurate, by asking one sender to give incorrect directions. The receiver then had to learn which sender was more reliable when deciding whether to rotate the block. After each move, the receiver was told whether they had made the right choice.

Five groups of three people played *Tetris* as part of the experiment, rotating the block so it fit into the row below with an average accuracy of about 81 per cent, including in the trials where the wrong instructions were sent (arxiv.org/abs/1809.08632).

Rao says that linking brains together to solve problems in this way may bring significant advances. "Extrapolating this idea, one could regard networks of connected brains as humanity's solution to overcoming the biological limits on human brain evolution," he says.

"We are probably in a pre-hive-mind phase," says Giulio Ruffini at Neuroelectrics in Barcelona, Spain. This new work is an incremental improvement on current technology, he says, but it is a step forward for non-invasive, brain-to-brain communication.

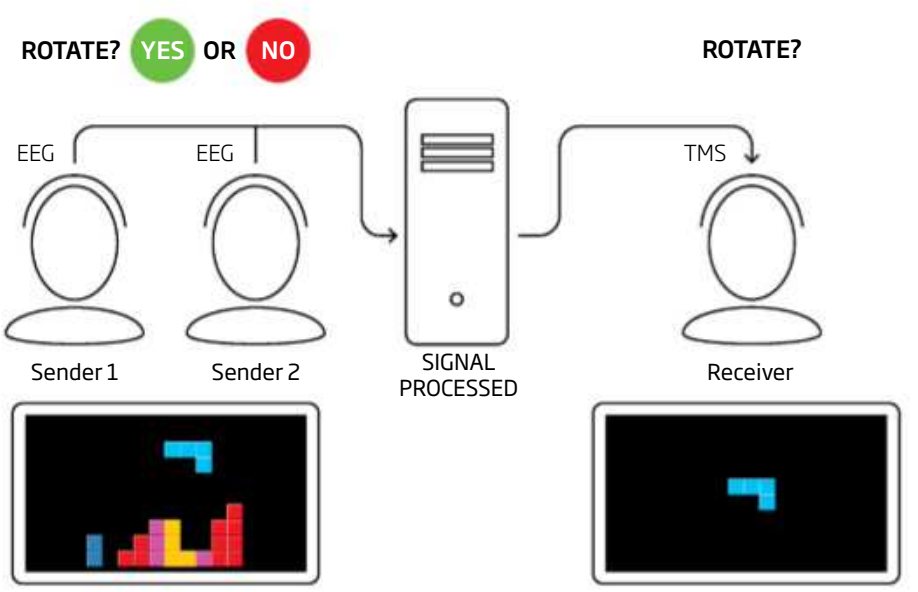
His colleague, Ana Maiques, says the most practical use for this technology would be helping people who cannot speak, either because of neurological or physical limitations. "Or you could use many brains to compute a difficult problem. Or to do something abstract like write a song. But I think that's wishful thinking," she says.

"Human brains can work together to solve a task that none of the brains individually could"

Attempts to merge human brains with computers – either with surgically implanted chips or non-invasive techniques like that developed by Rao and his colleagues – are being undertaken by companies such as Facebook and Elon Musk's Neuralink, a raft of start-ups, and the US military's research arm, the Defense Advanced Research Projects Agency (DARPA).

Don't go thinking you are going to incept an idea into a pal's mind any time soon, though. Facebook and DARPA have both said their early goals are to allow people to interact with software programs or type without using their hands. A mind-meld video game may still be years away. ■

Two players send their move recommendations via brain-reading caps to a third player, who must decide whether to rotate the block without being able to see the full state of play



BRIEFING

Can we limit warming to 1.5°C?

Michael Le Page

THE Intergovernmental Panel on Climate Change (IPCC) has released a report comparing the probable impacts of 1.5°C global warming with 2°C, and assessing what it would take to keep to this lower level. It synthesises all published research up to 15 May this year. Here's what you need to know.

Presumably we are much better off limiting warming to 1.5°C?
Right. But the consequences are still severe, especially for those countries most under threat of rising seas.

So can we limit warming to 1.5°C?
No.

The IPCC report says that?
It is not so categoric, but an early draft leaked in February came close: "There is very high likelihood that under current emission trajectories and current national pledges the Earth will warm more than 1.5°C above pre-industrial levels."

This was watered down in a later leaked draft: "There is no simple answer to the question of whether it is feasible to limit warming to 1.5°C… because feasibility has multiple dimensions…". Even this got cut from the final report.

Wait, watered down?
While the first drafts of IPCC reports are written by climate scientists, the final wording is the outcome of political negotiations among diplomats. We know from leaks that the US was one of the countries trying to water it down.

Why can't we limit warming to 1.5°C?
There are two aspects to this. First, if aliens landed tomorrow and took away all our fossil fuels, how much hotter would the planet still get? And if the aliens don't arrive, how much extra warming will we cause? According to a study out in August – too late to include in the report – the world might pass 1.5°C even if those aliens arrive. To be clear, the study does not say this is definitely the case, just that it is not impossible.

Game over, then?
Most of the cited studies suggest that there is only one way to keep warming below 1.5°C, or at least to get back down to this level later this century after overshooting it. This would not only require emissions to decline very rapidly – which would take radical and unprecedented change in every aspect of our lives including leaving oil and coal reserves in the ground – it would also mean having to actually remove CO_2 from the atmosphere.

So can't we just do that?
"Even if it is technically possible, without aligning the technical, political and social aspects of feasibility, it is not going to happen," says Glen Peters of the Center for International Climate Research in Oslo.

For now, global emissions are still increasing and we have yet to find a plausible way to remove huge quantities of CO_2 from the atmosphere. "There is a high chance that the level of CO_2 removal [required] might not be feasible," said the early draft.

OK, forget 1.5°C. How about 2°C?
According to the report, if countries make the cuts they say they will, we are on course for around 3°C of warming by 2100.

That's depressing…
It's not looking good. But even if the world doesn't meet either of the Paris targets, every reduction in emissions will help limit further warming. ■

CHESNOT/GETTY IMAGES

Targets set in Paris might not be enough to limit harm from warming

Strong signs of first ever exomoon

THE first moon to be spotted orbiting an exoplanet is slowly coming into view. The Hubble Space Telescope has found more evidence for an exomoon unlike any in the solar system.

In 2017, *New Scientist* reported that David Kipping and Alex Teachey at Columbia University in New York had spotted a possible exomoon in data from the Kepler Space Telescope, orbiting a distant planet called Kepler-1625b, which is thousands of light years away. It was enough to inspire the researchers to look more closely, but was not a discovery itself.

"We've had candidates in the past and investigated them, and most of them have evaporated," Kipping said at the time. But this exomoon candidate has not evaporated. Observations with Hubble showed two hints that it might really be there (*Science Advances*, doi.org/cvkb).

The first was that the exoplanet passed in front of its star 78 minutes earlier than we would expect if it had no moon, indicating that something is dragging on it gravitationally. The second was another, smaller dip in the star's light, after the dip caused by the planet passing by, suggesting two objects crossing the star.

These measurements indicate a gas giant about the size of Jupiter, orbited by a moon much bigger than any in our solar system. It is difficult to explain with our current view of how moons form in the solar system.

"Having a moon the size of Neptune with a Jupiter-sized planet sort of defies easy explanation"

"It will appear two times bigger than Earth's moon in the sky," says Teachey. "Having a moon the size of Neptune with a Jupiter-sized planet sort of defies easy explanation."

Like its planet, the moon is probably a gas giant, with an average temperature of around 27°C. If it weren't made of gas, that would mean that it could potentially be habitable, but Kipping cautions it is too early to say. "We don't know very much about the conditions on the moon at all – we don't even know for sure that the moon is there." Leah Crane ■

Industry slowed before Medieval crisis hit Europe

YEARS before the Great Famine and the Black Death hit 14th-century Europe, the continent was already in trouble. That is the conclusion of a massive new analysis of the timber used to construct historical European buildings, dated using tree ring methods.

Wood is routinely collected from archaeological sites and dated. Fredrik Charpentier Ljungqvist, a historian at Stockholm University in Sweden, and his colleagues scoured earlier studies to compile data on nearly 50,000 pieces of wood used for constructing buildings between AD 1250 and AD 1699. All of the wood came from Central and Western Europe.

Compiling the data allowed the researchers to establish a history of development over the 450-year period and compare it with the record of major historical events.

"The felling dates are basically a new historical source material for studying demographic, social and economic history," says Charpentier Ljungqvist.

The tree ring dates show a significant slowdown in building activity began around the year 1300. About 15 years later, a period known as the Late Medieval Crisis began. First came the Great Famine, followed a few decades later by the Black Death – a plague outbreak from 1346 to 1353 that killed millions of people across Eurasia.

Charpentier Ljungqvist and his colleagues say the slowdown in building from the year 1300 suggests society was in trouble – and the population stagnating – even before the Medieval crisis began. He says that bad harvests and other hardships had probably initiated the problem (*Journal of Archaeological Science*, doi.org/cvkf).

The researchers found slowdowns in building activity at other points in European history, particularly during the Thirty Years' War, fought from 1618 to 1648. Joshua Rapp Learn ■

LARRY W SMITH/EPA-EFE/REX/SHUTTERSTOCK

Donald Trump's rise to power may be down to his critical approach

We subconsciously treat naysayers as leaders

CRITICAL people often ascend to positions of leadership because their disregard for social niceties makes them seem powerful.

That is according to Eileen Chou at the University of Virginia, who explored people's attitudes towards "naysayers", those who express negative, critical views, and "cheerleaders", those who express positive, supportive views.

Across 11 experiments, she found that naysayers were considered more powerful and suitable for leadership roles than cheerleaders.

In one experiment, students were asked to read positive and negative restaurant reviews. They rated the author of the negative review as appearing more powerful, independent and able to express their real opinions about the restaurant.

In another experiment, students were placed in groups and asked to review an artwork. Each group contained two actors, one with critical views and the other with appreciative views. The students rated the critical actor as appearing more dominant and in control, and were more likely to elect them as group leader.

A third experiment asked online volunteers to read real quotes from past US presidential candidates. Without knowing who said them, the participants rated negative quotes like "these are very difficult times and challenges for America" as signalling greater power and leadership potential.

"Openly critical individuals may seem to transcend social constraints and so be seen as more powerful"

Despite these endorsements, the participants rated naysayers as being less likeable than cheerleaders. But this appeared to be offset by their respect for the naysayers' courage to go against the grain (*Journal of Personality and Social Psychology*, doi.org/gd8575).

Since negativity is generally considered impolite, openly critical individuals may seem to transcend social constraints and therefore be more powerful, says Chou. This may lead us to instinctively treat them as leaders, even if we don't like them.

The findings may explain why negative, bullying types are able to rise to positions of power and influence, says Chou.

They may also partially explain the success of Donald Trump, who disregards convention and appears unafraid to be openly critical, says Frank Mols at the University of Queensland in Australia. "His ability to speak his mind seems to appeal to voters, who interpret his boldness as a sign of authenticity," he says.

However, it would be simplistic to conclude that Trump was elected US president because voters responded in an instinctive way to his negativity and resulting appearance of power, says Mols. To suggest that Trump supporters were driven by subconscious impulses would be to dismiss the fact that they felt they had legitimate reasons – like concerns about immigration – to vote for him, he says.

Chou says it is important to note that the findings are only relevant to the initial establishment of power. Once naysayers become leaders, their negativity may make them unpopular and lead to their fall, she says. "We are conducting further research to examine this possibility," she says.

Moreover, the results shouldn't be interpreted as meaning we are doomed to always have naysayers as national leaders, says Chou. In countries where the public discourse has turned negative, individuals who express positive, optimistic ideals may seem more powerful because of their opposing views, she says. This may explain Barack Obama's success in being elected US president in 2008 with his message of hope and positivity, she says. **Alice Klein** ■

ANDREW TESTA/PANOS

Food handling hygiene is vital to keep pathogens out of food

Spritz to check for food safety

Douglas Heaven

USE-BY dates are the best guide we have for telling whether food is still safe to eat, but they aren't particularly accurate. A sticker that senses harmful bacteria may soon provide a more precise way to check if what's in your fridge is fit for the plate, reducing waste.

London-based start-up Fresh Check has already been testing its spray version of the new safety system in abattoirs, restaurant kitchens and sandwich-filling facilities since April, where it can detect contamination on food handling surfaces. The product has now been given the OK by Campden BRI, an independent food safety authority, and Fresh Check made its first sale earlier this month, to a ready-meal firm.

Such safety checks are usually done with swabs, plastic sticks containing an enzyme that reacts with adenosine triphosphate, a molecule made by all living cells including bacteria. But this method is expensive and fiddly, says John Simpson at Fresh Check.

Instead of a biological reaction, Fresh Check's spray uses a chemical reaction that flags the presence of a protein produced by bacteria but not mammalian cells. It is cheaper and longer lasting than a swab test, meaning it can be kept close to hand and used for frequent spot checks. Spray it on a surface and the liquid changes colour if bacteria are present.

Bacteria that can cause illness, such as listeria and some strains of *E. coli*, are quite prevalent, says Simpson, who is "hoping for a bump in hygiene standards".

Food safety professional Lisa Ackerley was an early fan and has been advising the company. She thinks the spray will be especially useful for testing surfaces used for preparing food that is ready to eat, such as a food slicer in a deli or a countertop where sushi is made. "You can't judge a surface by visible cleanliness," she says.

Ackerley has also carried out hygiene checks in hotels and sees a use for the spray there, to let managers see if rooms have been properly cleaned. "I've quite often found the cups or glasses are dirtier than the toilet," she says.

Fresh Check is now planning to develop hand wipes that use the chemical test. It also wants to make stickers containing the spray that can be put inside food packaging. These would change colour when meat or fish were no longer safe to eat, giving a more precise way to monitor freshness than a use-by date.

People in the UK throw away around 41 per cent – or 2 million tonnes – of the food they buy each year because they think it is no longer safe to eat, according to estimates by the charity Waste and Resources Action Programme (WRAP). A third of that food was binned because of advice such as use-by dates on packaging, says Andrew Parry at WRAP. However, such food may often still be safe.

Fresh Check is talking to supermarkets about placing their stickers in packaging. But costs are still too high for the big chains to bite. Each food package costs them a fraction of a pence to make and anything that increases that even by a tiny amount cuts into their margins, says Simpson. ■

Faecal swaps may help organ transplants

ONE key to organ transplant success might lie in an unexpected place: the gut. Giving mice a faecal transplant stopped them rejecting a donor heart.

This might be because bacteria in the bowel help regulate the immune system and stop it from attacking transplanted tissue. Finding out exactly what is going on could lead to new medicines to stop organ rejection, says Jonathan Bromberg at the University of Maryland.

Organ transplants are given to people with failing organs such as the heart, kidney or liver. Recipients take powerful drugs to stop their immune systems recognising the donated organ as foreign and rejecting it. But even so, after several years the new organ is often scarred and inflamed because of low-level immune attack.

To see how gut bacteria affected organ transplant success, Bromberg's team gave mice two different types of faecal transplant. One group had a dose of bacteria-loaded faeces from pregnant animals, as their immune system is known to be naturally suppressed during pregnancy. The other group got a faecal transplant from non-pregnant mice.

Then the mice had a heart from an unrelated mouse transplanted into their belly, without removing their original heart – this is a common way of testing new transplant drugs.

The second heart was kept alive for 40 days in all five animals that got the faecal transplant from pregnant mice. Only one out of five mice in the other group had a donor heart that lasted that long (*Clinical Investigation Insight*, doi.org/cvnq). It seems as though gut bacteria from pregnant mice turn down the "volume knob" of the immune system, says Bromberg.

"Despite drugs to suppress immune system attack, transplant organs still have scarring and inflammation"

He says that gut bacteria are in contact with immune cells in the walls of the bowel and can push immune system activity up or down. His next step is to find out more about how the faecal transplants had this effect.

Clare Wilson ■

Where did we come from?
How did it all begin?

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Introduction by **Professor Stephen Hawking**

New Scientist

Milk tolerant gene taking hold in Chile

Michael Marshall

A GROUP of people living in Chile are evolving the ability to digest milk as adults, as most Europeans did thousands of years ago. The finding shows evolution is still changing us now and challenges our ideas about why this kind of milk digestion evolved.

Nicolás Montalva at the Universidad Mayor in Santiago, Chile, and his colleagues have studied the people living in Chile's Coquimbo region, between the Atacama desert and the country's central valleys.

The people drink a lot of goat's milk – which is surprising because native Americans cannot digest milk properly.

Humans have an enzyme called lactase that breaks down lactose, a sugar in milk. Lactase production is usually turned off once a baby is weaned. But in the past 10,000 years, some groups, particularly in Europe, acquired mutations that keep lactase active, allowing adults to digest milk. This is called lactase persistence.

Many non-Europeans lack these mutations and suffer symptoms like diarrhoea and flatulence if they drink milk.

"In South America, there has been no history of milking of mammals," says study co-author Dallas Swallow of University College London. Only when Europeans arrived 500 years ago did this change. The colonisers, who brought animals like goats with them, interbred with local people.

In 2015, Montalva and his team showed that 40 per cent of the people in Coquimbo are lactase-persistent. Now they have taken a closer look at people in the region.

They gathered DNA samples and other data from a total of 451 individuals. Like most Chilean populations, the DNA of these people was about 50:50 European and native American.

"The lactase-persistence mutation carried by people in Coquimbo has spread by natural selection"

All those who had lactase persistence had the same European mutation. The mutation itself, and the DNA around it, looked almost identical in carriers. This level of genetic stability is a sign that the mutation serves a useful purpose in carriers and has been favoured by natural selection over the past few centuries (*Annals of Human Genetics*, doi.org/cvj9).

The team also looked at the question of why natural selection favours lactase persistence. The leading idea is that it opens up milk as a new source of food, so lactase-persistent people ought to be better nourished. Montalva's team found that, on average, Coquimbo men who can drink milk are heavier than those who can't – suggesting they have a more nutritious diet. However, there was no such trend among women. So maybe it isn't about extra calories, says Swallow, but the micronutrients in milk.

However, Laure Ségurel at the Museum of Mankind in Paris, France, has another idea. "I'm not really convinced it has so much to do with diet," she says. She thinks people living in such close contact with livestock are at increased risk of catching animal diseases and drinking their milk might prime the people's immune system to protect against those diseases. ■

XINHUA/ALAMY

A Chilean population is evolving to cope with drinking milk as adults

Get a reassuring caress from your phone

WHAT if smartphones had a robotic limb? Many inventions start with a question that nobody else had ever thought to ask. Few of them end up being quite as creepy as MobiLimb.

Created by Marc Teyssier at the University of Paris-Saclay in France and his colleagues, MobiLimb looks like a mechanical finger, with knuckles that let it bend and beckon.

The appendage plugs into a USB port on your smartphone or tablet and can be used as an additional way to interact with your device.

MobiLimb can also be covered with different sheaths. A skin-like cover, complete with fingernail tip, makes the finger's caresses appear more lifelike. A fur covering makes the appendage look like a tail – tickle an animal avatar on the screen and this tail wags enthusiastically.

The limb even allows your phone to crawl across surfaces, pulling itself along like Thing, the disembodied hand in *The Addams Family*.

The team's aim was to overcome some sensory limitations of mobile devices. "In real life, we use touch to convey emotions," says Teyssier. "A robotic extension like MobiLimb would be capable of transmitting a remote touch from someone."

Teyssier's favourite accessory for the limb is the skin-like sheath because it lets you interact with the phone in a natural way, he says. Technology may have become smarter than ever, but it can still be cold and mechanical. More "organic" tech could help it be more lifelike, he says.

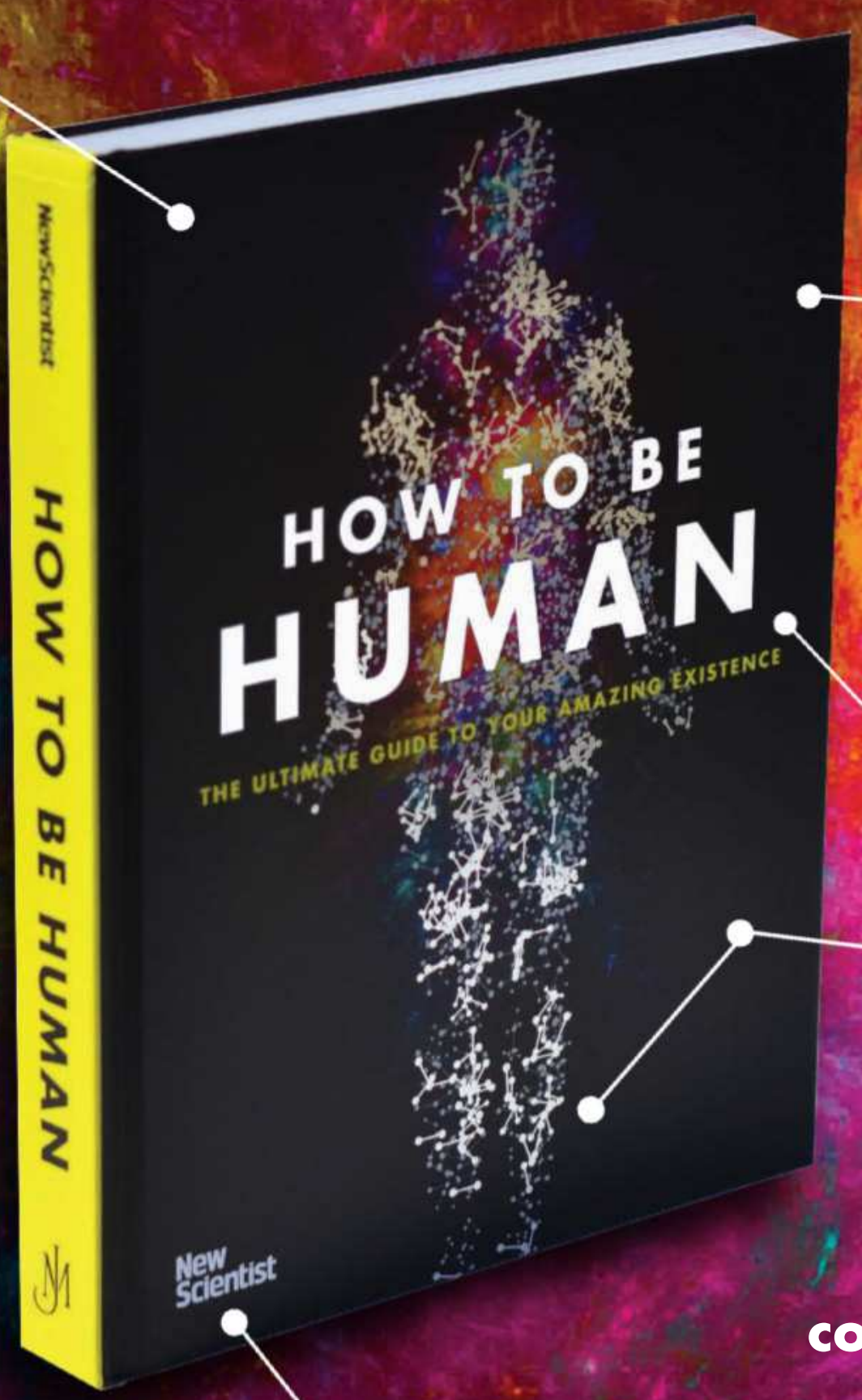
The team will present the work at the User Interface Software and Technology Symposium in Berlin this month. Douglas Heaven ■

MARC TEYSSIER ET AL.

It's creepy and it's kooky, it's a smartphone with a MobiLimb

Humanity will need the equivalent of 2 Earths to support itself by 2030.

People lying down solve anagrams in 10% less time than people standing up.



About 6 in 100 babies (mostly boys) are born with an extra nipple.

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Cassini reveals the secrets of Saturn

Leah Crane

CASSINI is dead, but its legacy lives on. Before the NASA spacecraft plunged into Saturn and burned up in September 2017, it made 22 daring final orbits, swooping between the planet and its rings in a mission called the Grand Finale. Now, researchers writing in the journal *Science* have analysed the data it collected and revealed a few surprises.

SATURN'S MAGNETIC FIELD IS WEIRD

The magnetic fields of planets in our solar system are all tilted to some extent, but Saturn's magnetic field seems to be perfectly straight. Current theories suggest that should be impossible (doi.org/cvj4).

"If you don't have a tilt, you would expect the magnetic field to start dying away," says Michele Dougherty at Imperial College London.

That might mean that Saturn produces its magnetic field differently from the other planets in our solar system, maybe with many onion-like layers of flowing particles producing the field instead of a single zone.

SATURN'S EMPTY SPACE ACTUALLY ISN'T

Even the seemingly empty space between Saturn's surface and its rings is more exciting than we thought. "There's this connection between the rings and the upper atmosphere of Saturn that we just didn't think would be there," says Dougherty. "That was a complete surprise."

That connection is in the form of electric currents that flow between the rings and the upper atmosphere. It is not yet clear what is causing them, says Dougherty.

The currents aren't all: there is also a belt of radiation coming from energetic particles trapped between the rings and the planet (doi.org/cvj5). It is similar to Earth's Van Allen belts, which can be dangerous for astronauts and spacecraft that pass through them, says William Kurth at the University of Iowa. Figuring out how the belt formed could help us understand similar zones of radiation around other planets.

SATURN'S RINGS MAKE IT RAIN

Between Saturn's innermost rings and the top of its atmosphere is a deluge of tiny particles falling down from the rings, called ring rain (doi.org/cvj6). Cassini found that this rain deposits up to 45,000 kilograms of dust, ice and gas around Saturn's equator every second – the equivalent of about 1800 cars falling into Saturn every minute (doi.org/cvj7).

While the rings are made of mostly water ice, the rain is much more diverse, with ammonia, nitrogen, methane and even more complex organic particles. This may affect the chemistry of the top layers of Saturn, says Hunter Waite at Southwest Research Institute in Texas (doi.org/cvj8).

"Saturn's rings rain down up to 45,000 kilograms of dust, ice and gas around its equator every second"

This effect was not obvious before Cassini because it is spread over a large area. "It's not like rain, really – more like a really fine mist that you can't even really see," says Waite. "The particles are so small that I don't think you'd feel them if you were floating between Saturn and its rings." ■

JPL/NASA

The Cassini probe spent 13 years in orbit around the gas giant

Tap your fingers to mess with time perception

WHEN you move your body in time to a rhythm, your perception of time stretches and contracts. The finding might help us pin down which parts of the brain control our internal clocks.

Alice Tomassini at the Italian Institute of Technology and her colleagues asked 16 participants to listen to four beats, each of them one second apart, and then tap out four additional beats with their finger to keep the rhythm going. Before the tapping test, the participants were taught to familiarise themselves with a yellow light that would flash twice, with a 150-millisecond gap between the two flashes.

During the test, the yellow light flashed twice between a participant's third and fourth finger taps. However, the gap between flashes varied from 70 to 300 milliseconds. Participants were asked to judge each time whether the gap was longer or shorter than the 150-millisecond interval they had become familiar with.

There was an additional factor at play: sometimes the yellow flashes happened just after a participant had made their third finger tap or just before they made their fourth finger tap, and sometimes the flashes came roughly halfway through the time interval between the two finger taps.

Tomassini and her team found that the participants consistently underestimated the length of the gap when the flashes were presented just after their third finger tap or just before the fourth finger tap, and overestimated the gap when the flashes were halfway through the interval between taps. In other words, they perceived time as contracting near the finger taps, and expanding midway through the interval between taps (*Proceedings of the Royal Society B*, doi.org/cvkd).

Our bodies are governed by several internal clocks. These results hint that our motor system may be the master clock. Chelsea Whyte ■

FIELD NOTES Santa Cruz, the Galapagos Islands

Ecological tension in the Galapagos

Adam Popescu

I HAVE been walking for hours, trekking through the rainy highlands of Santa Cruz in search of a giant. I am on one of the biggest islands in the Galapagos, the archipelago known for its strange species: marine iguanas, the northern hemisphere's only penguins – and the world's largest tortoises. It is these lumbering giants I am looking for.

The Galapagos Islands are home to 10 types of giant tortoise, some weighing 400 kilograms. But despite their size they aren't as easy to find as I had anticipated.

Many regard the Galapagos as a living zoo, little changed since Charles Darwin visited here in the 1830s. The reality is starker. Climate change, invasive plants and animals, and conflicts between humans and wildlife are among the many problems. The Galapagos National Park allows human settlements on only four islands, and 97 per cent of all land here remains protected. But the human impact on the remaining 3 per cent is significant.

I see it in the yapping guard dogs and the fences that protect crops and disrupt tortoise migratory routes and feeding patterns. My only encounters so far have been with farmers and their cows, goats and chickens. I head further into the bush until the misty rain restarts. Tired and wet and yet to find a tortoise, I return to the road. Thirty minutes later I am on a packed bus, hurtling along the highway that slices through jungle, descending towards the town of Puerto Ayora.

And then I finally see them. One, two, three, four – I lose count after a dozen. The giant tortoises lumber along the side of the road near town. Life is apparently easier for them nearer to roads and towns than it is in their remote highland homes. That said, they must return to the highlands to lay eggs, and the presence of even a few thousand farmers in the hills means the tortoises need to travel further to find a good spot.

"The agricultural zone is overlapping with the migration paths of tortoises," says Ainoa Nieto of the Charles Darwin Foundation in Puerto Ayora. She has been tracking the movements of Galapagos tortoises since 2011, and monitors their health. "The roads are creating barriers, we have some tortoises hit by cars. And farmers build fences because tortoises love eating their crops."

"Invasive species like ants, rats, feral dogs, donkeys and wild pigs love to eat tortoise eggs"

But the real trouble isn't what tortoises are dining on but who they are dining with. "It's typical to see cows and tortoises together eating the same things," says Nieto. Aside from competition for food, this raises the risk tortoises will catch new pathogens.

Proximity to humans has also led to antibacterial resistant infections in tortoises, a health threat for humans and wildlife because tortoises roam widely.

Then there are the invasive species. "Ants, rats, feral dogs, donkeys, wild pigs, they love to eat tortoise eggs," says Nieto.

Climate change also poses a problem. Higher temperatures mean more tortoises hatch as females, says Nieto, because tortoise gender is determined by egg incubation temperatures. This may threaten the viability of populations.

But there is still hope. In 1965, the Fausto Llerena Tortoise Center was founded to save the 200-odd adult tortoises left on Pinzón Island. Since 1970, thousands of tortoises have been reared by the National Park and reintroduced to 11 islands. The open-air breeding centre is a visible sign of the support tortoises now receive.

There is an uncomfortable balance, though: the centre is a tourist attraction, helping encourage more visitors to the island – which is arguably a key reason why the tortoises are now in a fight for survival.

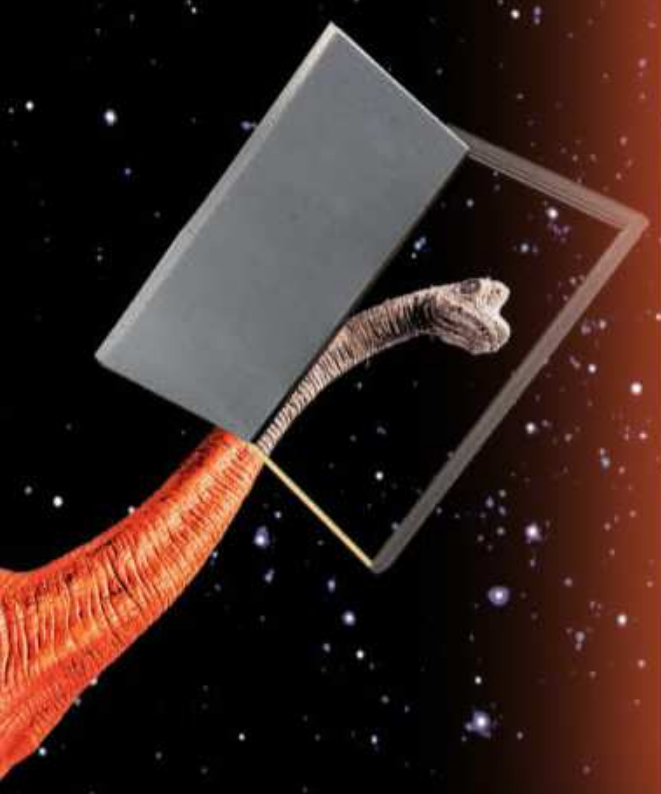
"Population is increasing in Galapagos," says Nieto. "I've lived here seven years and there's a lot more hotels, more buildings."

On my return home I get in touch with Stephen Blake at Saint Louis University in Missouri, who has spent nearly a decade studying the tortoises. "It's a really fraught issue," he says, but the situation was arguably worse a century ago. People can moan about breeding centres, he says, but the bottom line is they brought one species – the Hood Island tortoise – back from the brink of extinction. "And they have made significant contributions to keeping others going." ■

PETE OXFORD/MINDEN

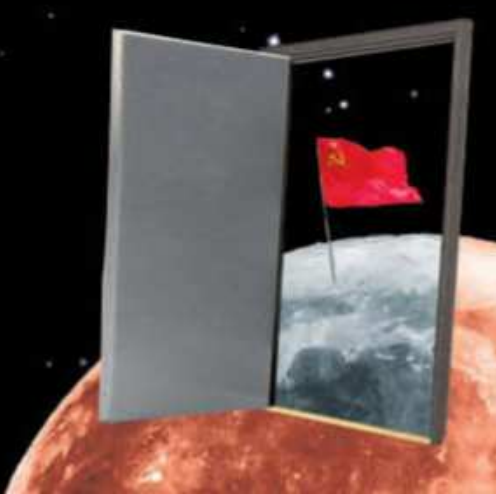
Giant Galapagos tortoises, perhaps unwisely, hang out near roads

WHAT IF TIME STARTED FLOWING BACKWARDS?



WHAT IF THE RUSSIANS GOT TO THE MOON FIRST?

WHAT IF DINOSAURS STILL RULED THE EARTH?



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Building better cities

Thanks to clever chemistry and innovative engineering, the cities of the future are being fashioned from cleaner, greener concrete

By 2050, the world will be home to 9.6 billion people, and 70 per cent of them will live in cities. Those cities will need to be human-friendly, with easy-to-reach workspaces and leisure zones that make urban life relaxing and enjoyable. They will also need transport and sewerage infrastructures, and housing that works for everyone.

The cities of the future will have to be bigger, better and smarter than anything built before. In some ways they are already under construction: think of London's Shard tower, or Dubai's Burj Khalifa – the world's tallest building – or even the awe-inspiring complexity of hidden structures such as Crossrail's 42-kilometre web of new rail tunnels under London.

All of these are emblematic of the smart city revolution. And at the heart of this change is one of the proverbial building blocks of modern settlements: concrete, the material that these cities will be fashioned from.

Clever chemistry is making concrete more advanced than ever. "We can build higher, we can build slimmer, we can build further underground, and we can build for longer," says Ian Ellis at BASF, one of the world's largest chemical companies. Ellis manages the concrete admixtures technical services that BASF offers in the UK, Ireland and Benelux.

Ellis is part of a global BASF team that has developed an array of polymers and associated admixtures capable of changing concrete's properties – increasing its strength, altering its workable lifetime, improving its rheology and even allowing it to be sprayed onto newly excavated earth.

It is this last property that allowed the huge Crossrail tunnels to be built so quickly and efficiently. Every time the boring machines excavated a metre or so of the tunnel, robots sprayed a 400-millimetre layer of concrete onto the newly exposed London clay. As the concrete emerged from the spray nozzle, it mixed with a BASF accelerator that starts the setting process. "The millisecond the concrete is in the air, it starts to set," says Richard Foord, project manager for BASF's underground construction in the UK and Ireland.

This newfound control over concrete's setting time is proving a hit with engineers looking to create what would once have been seen as impossible builds. Even the process of getting concrete to the construction site is being transformed by chemical intervention. If a truck gets snarled up in traffic, the concrete might begin to set too early, but polymers in the admixture can prevent this.

Building upwards can create problems too. Much of the concrete poured for the Burj Khalifa had to be pumped up to 600 metres above ground. "By the time it gets up there it's already more than one hour old," Ellis says. And the construction took place in the desert, with the structure exposed to Dubai's blazing sun.

All this is possible using polymers that help the particles of cement bind together when it is meant to set, or keep them apart when it is not. But getting the mixture exactly right is a difficult task.

It's this kind of challenge that Ellis and Foord relish. They liaise with polymer chemists at BASF laboratories around the world to meet the increasingly tough demands of construction engineers. "Tell us what you want the concrete to

IMAGE COURTESY OF CROSSRAIL/FLICKR

Smart cities: The Shard in London (left), the Burj Khalifa in Dubai, the Queensferry Crossing, Edinburgh (top) and Crossrail tunnelling

do, and we will do our utmost to make it happen," Ellis says.

These days, the engineers' demands include ecological considerations. Tideway, London's "supersewer" – a 25-kilometre tunnel 60 metres underground – provides a good example. The sewer will directly improve London's environment, reducing sewage dumps into the river Thames by 95 percent, and even the materials used to build it are arriving on site in the most environmentally friendly way possible. "We've had to reinvent the way we move and supply concrete," Foord says.

BASF's involvement in the building of the new Queensferry Crossing across the river Forth also tackled environmental issues: to minimise the project's carbon footprint, the concrete relied on local materials. That in turn meant finding polymer add-ins and other chemical fixes that would transform the properties of those materials, giving the resulting concrete the strength, durability and workability required.

Technological innovations also help temper concrete's innate environmental impact. Making the cement used in concrete involves heating ground-up minerals to ultra-high temperatures in furnaces that burn fossil fuels and release enormous quantities of carbon dioxide and other greenhouse gases. Cement production is responsible for around 8 per cent of global CO_2 emissions – as well as being increasingly expensive.

That's why BASF laboratories have developed products that replace much of the cement with materials such as limestone filler, fly ash, a by-product of coal-fuelled power plants, or powdered blast furnace slag from steel production.

Despite all the challenges facing construction in the 21st century, modern concrete still looks good: it resists attack from pollutants in city air, and allows construction to be eco-efficient, faster and more cost-efficient. Perhaps most excitingly, though, it makes city life better.

More at: www.wecreatechemistry.com

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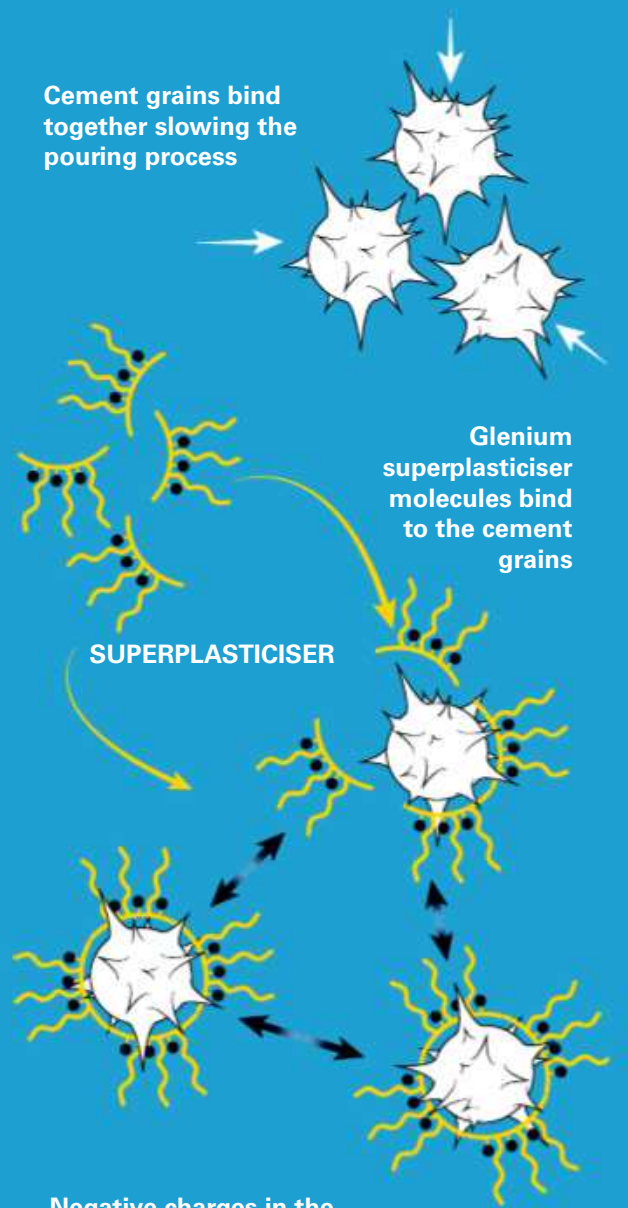

Concrete chemistry

Polymers make it possible to pour enormous volumes of concrete into a single structure. Building the basement of the Shard, for instance, took almost a whole weekend: over a 36-hour period, London Concrete poured 5400 cubic metres of concrete down from ground level. BASF polymers ensured that it set as one continuous structure. "The concrete poured first had to have a longer setting time than the concrete poured towards the end," Ellis says.

Another type of polymer, a superplasticiser, can improve the way concrete spreads by preventing cement particles from binding to each other. This makes the mixture less viscous (see diagram) so that it spreads further when it is poured. BASF markets such admixtures under the MasterGlenium brand.

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ANDREW BROCK ET AL.

AI fakes its own glorious images of the natural world

THESE may look like gorgeous nature photographs, but the scenes they capture don't actually exist – artificial intelligence dreamed them up.

Andrew Brock of Heriot-Watt University, UK, and his colleagues at Google's sister firm DeepMind created a generative adversarial network (GAN), an algorithm that pits two AIs against each other to produce new images.

The GAN, known as BigGAN, was first trained on thousands of images linked to particular words, such as butterfly. Normally, systems like this are only given about 64 images per word, but BigGAN's massive processing power means it can cope with 2000. Once trained, BigGAN then created its own images related to each word (arxiv.org/abs/1809.11096).

"A lot of the images are photorealistic, and the algorithm has managed to do hundreds of different items," says Janelle Shane, a researcher who has previously used AI to create April Fool's pranks.

Some are good enough to hoodwink even BigGAN's creator. During the project, Brock came across a strip of images of jaguars and bears that BigGAN had generated and mistook it for a Google Image search result.

However, the AI still struggles with some parts of nature. For example, it trips up over the number of legs on a spider, giving them 20 or more in some instances, or adding too many eyes to frogs.

Icy daggers await us on parts of Europa

PARTS of Europa may be covered in long blades of ice that could make exploring this frigid moon of Jupiter more dangerous.

In the driest, coldest places on Earth, sunlight hitting small depressions in ice and snow can eventually create pointy frozen formations called penitentes, which can reach several metres tall. Europa is much colder and much drier than Earth because it has almost no atmosphere, and it has lower gravity, so Daniel Hobley at Cardiff University, UK, and his colleagues calculated that it could build penitentes 15 metres high with holes about 7.5 metres across between them (*Nature Geoscience*, doi.org/cvkg).

Because penitentes grow faster when the sun is directly overhead, they are likely to appear mostly around the equator, like on Earth, giving the moon a spiked belt around its middle.

This could be a problem for any spacecraft hoping to land in the region, either because of the spikes or the gaps between them that might trap a spacecraft. "You can imagine something getting lodged in there and flopping around," Hobley says.

"But if you already know the surface is likely to be spiky and full of holes, you can probably plan around that," he adds.

VR can ease fear of public speaking

HATE public speaking? Practising in front of a virtual crowd may help you conquer your fears.

A third of people feel excessive anxiety when they have to speak in front of others. Philip Lindner at Stockholm University in Sweden and his colleagues wanted to see if virtual reality could provide a safe environment in which people can face these fears.

They recruited 50 adults with public speaking anxiety to try a training app. It works via a VR headset that allows them to pretend they are addressing a large hall of people, a small office meeting, or a wedding party. After 3 hours, the participants reported feeling significantly more confident.

They also felt less nervous, shaky and sweaty when they were given real-life exercises to try like asking questions in meetings or giving presentations (*Journal of Anxiety Disorders*, doi.org/cvkn).

Super armour helps coelacanths endure

THE armour of a coelacanth has a remarkable structure that may help explain how these fish have dodged extinction and lasted for hundreds of millions of years.

Robert Ritchie at Lawrence Berkeley National Laboratory in California and his colleagues examined coelacanth scales and found a surprisingly complex inner structure. Beneath a tough mineral layer are bundles of collagen in a twisted structure similar to a spiral staircase.

When pressure is applied to the scales, such as during a bite, the bundles absorb energy. The team also found fibres between these bundles that help stop the spread of cracks in the mineral layer (*Advanced Functional Materials*, doi.org/cvnt).

Goblin boosts the hunt for Planet X

A DWARF planet called the Goblin has been found orbiting the sun beyond Pluto, and its elongated orbit hints that long-sought Planet X may also be travelling through the outer reaches of the solar system.

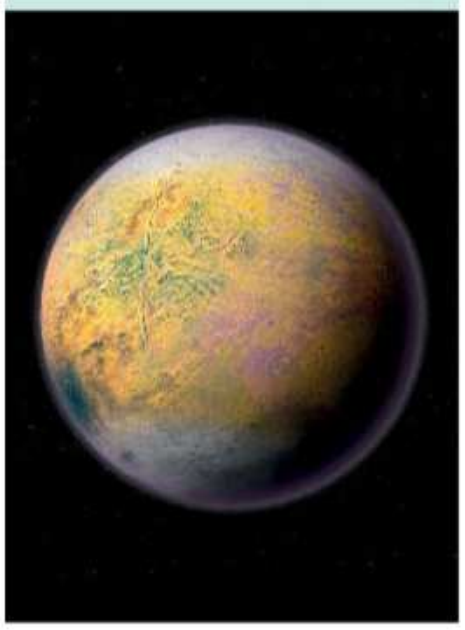
The dwarf planet, officially called 2015 TG387, is about 300 kilometres in diameter and is probably a ball of ice. It was first spotted by David Tholen at the University of Hawaii and his colleagues using the Subaru telescope in Hawaii in October 2015, hence its Halloween-themed name. But the International Astronomical Union's Minor Planet Center only recently announced the discovery.

The farthest flung parts of the Goblin's orbit are 2300 times as far from the sun as Earth is. One Goblin year is 40,000 of our years.

The team found the dwarf planet during its hunt for the hypothetical Planet X, a large planet believed to be at the edge of the solar system.

If such a planet were present, its gravity would tug on smaller objects such as the Goblin (depicted below) as they pass, potentially herding them into a cluster orbiting the sun together – just like the cluster the Goblin was found in.

The team ran simulations that included a super-Earth-like planet in the distant solar system, and found that it would ensure the Goblin stays on its highly elongated orbit.



R. MOLAR CANDANOSA/S. SHEPPARD/CARNEGIE INSTITUTION FOR SCIENCE

Falling rocks can create a blast that only nuclear bombs beat

WEIRD rockfalls that can explode more intensely than the most potent conventional bombs are more common than we thought. Such extreme events produce a shock wave that can snap trees growing hundreds of metres away.

"They're extremely weird phenomena, which have been somehow overlooked," says Fabio De Blasio at the University of Milano-Bicocca in Italy.

The first recorded example took place in Yosemite National Park, California, on 10 July 1996. Two large masses of rock fell from Glacier Point and plummeted 665 metres. On hitting the ground, they released a blast of air that snapped or toppled about 1000 trees up to half a kilometre away. That was the subject of a study published in 2000, although such events remained a curiosity.

Now De Blasio and his colleagues have identified 21 other "extremely energetic rockfalls" from the past two decades, mostly in the European Alps and the Dolomites in Italy. They argue that this makes these events less rare than once thought.

To cause such a shock wave, on the order of 10,000 cubic metres of rock has to fall several hundred metres. The impact is so violent that the rocks are smashed into powder. "Typically they develop in areas where erosion has been quite fast," says De Blasio.

Based on calculations, De Blasio and his colleagues estimate that just one of these extreme rockfalls can release more than 80 billion joules of energy, more than any non-nuclear bomb (*Journal of Geophysical Research: Earth Surface*, doi.org/cvkj).

Trial drug improves IVF success rates

PEOPLE undergoing IVF may soon have a better chance of having a baby thanks to a drug that helps embryos implant in the uterus.

In a trial involving almost 800 women at fertility clinics in Europe, the drug nolasiban raised IVF success rates.

Each participant took a placebo or a nolasiban pill 4 hours before they had an embryo transferred to their uterus. Almost 45 per cent of those in the nolasiban group went on to have a baby, compared with 33 per cent in the placebo group.

The results represent potentially the biggest advance in IVF in 25 years, says Ernest Loumaye at ObsEva, the firm developing the drug and that funded the research. He says another trial is planned this year and the drug may be available by late 2020.

Nolasiban blocks the hormone oxytocin. The result is more blood flow to the uterus, which reduces contractions that can affect implantation, says Loumaye.

The initial results are promising but more trials are needed before getting too excited, says Peter Illingworth at IVF Australia. "I'd also advise caution until the full experimental details of the latest trial are released."

TOSHIFUMI KITAMURA/AFP/GETTY IMAGES

T. rex wasn't the king of dino brains

TYRANNOSAURUS REX may have been one of the biggest and fiercest dinosaurs, but it had a simpler brain than an earlier, smaller tyrannosaur.

Martin Kundrát at Pavol Jozef Safarik University in Slovakia and his colleagues wanted to know how tyrannosaur brains changed as they went from small predators to giants like *T. rex,* which could grow to 12 metres. To investigate, they looked at the skull of a 125-million-year-old fossil of *Dilong paradoxus* – a 1.6-metre-long tyrannosaur that predated *T. rex* by 50 million years. Then they did the same for a 67-million-year-old fossil of *T. rex*.

The team found a shift in brain shape as tyrannosaurs evolved and enlarged, from an S-shaped brain in *D. paradoxus* to what Kundrát describes as a "simpler", more linear shape in *T. rex*.

Although *T. rex* had a brain 62 times bigger than *D. paradoxus*'s, it had a relatively smaller forebrain and midbrain, regions linked with agility. *T. rex* also had comparatively smaller eyes and brain region associated with vision than *D. paradoxus*. But it had a larger brain region linked to smell (*Historical Biology*, doi.org/cvhz).

Knowledge means power

Advances in artificial intelligence could lead to a massive growth in energy use, warns **Michael Le Page**

ARTIFICIAL intelligence breakthroughs have become a regular occurrence in recent years. One of the most impressive achievements so far was in 2016, when Google DeepMind's AlphaGo AI beat champion Lee Sedol at one of the world's most complex games, Go.

The feat made headlines around the world as an example of machines besting humans, but in some sense it wasn't a fair fight. Sedol's brain would have been consuming around 20 watts of power, with only a fraction of that being used for the game itself. By contrast, AlphaGo was using some 5000 watts.

It isn't widely appreciated how incredibly energy hungry AI is. If you ran AlphaGo non-stop for a year, the electricity alone would cost about £6000. That doesn't matter for one-off events, like an epic Go showdown. But it does matter if billions of people want their smartphones to be truly smart, or have their cars drive themselves.

Many potential uses of AI simply won't become widespread if they require too much energy. On the flip side, if the uses are so desirable or profitable that people don't care about the costs, it could lead to a surge in electricity consumption and make it even harder to limit further warming of the planet.

"Deep learning involves performing ever more computations on ever more data"

AI consumes so much energy because the technique behind these recent breakthroughs, deep learning, involves performing ever more computations on ever more data. "The models are getting deeper and getting wider, and they use more and more energy to compute," says Max Welling of the University of Amsterdam, the Netherlands.

Take image recognition, for instance. This is done by training neural nets that mimic the brain.

20 per cent

The additional energy consumption AI adds to a self-driving car

Images are split up and fed into the first layer of the net, which might look for edges. The results get passed to the next layer, which might look for simple shapes such as a dog's tail or a letter, and so on.

The more you want the net to recognise, the more layers it must have and the more complex it has to be. Identifying different breeds of dogs, say, is a much harder task than simply recognising dogs.

The most sophisticated neural nets have grown "outrageously large", as a recent paper put it. Their complexity can be measured by the number of parameters in the net – and some now have more than 100 billion parameters.

This is important for two reasons, says Welling. First, energy is money. "There is an economic ceiling to what is a useful AI technology," he says. For big online services like Facebook and Google, the cost per use of AI has to be tiny – in the region of a thousandth of a penny.

Second, mobile devices can only use so much energy. It is not just about battery life, but the limit that comes from ensuring devices don't get too hot, Welling says.

This is why voice assistants like Siri or Alexa need an internet connection for full functionality – your phone or smart speaker doesn't have the processing power needed to run the AI locally, or the space to store all the associated data.

All this means that our use of AI can't keep expanding indefinitely unless we reduce the energy requirements. "What matters is how much intelligence we can squeeze out per joule," says Welling.

Take self-driving cars. These require all sorts of extra systems, from cameras to radar, that use power and also increase weight and drag, further increasing energy use. But the single largest consumer of energy besides the engine is the processor running the AI.

Battery busters

According to a study out earlier this year, self-driving cars could use up to 20 per cent more energy than conventional cars. That is a big issue for a battery-powered car, limiting its range and increasing running costs. What's more, the study assumes the AI processor consumes about 200 watts, even though current prototypes consume in excess of 2000 watts.

For taxi companies using AI to directly replace human drivers, the savings in wages would probably far outweigh the higher energy costs. But for ordinary car owners this would be a major issue.

Thankfully, people are already working to improve the efficiency of deep-learning algorithms, by getting rid of unnecessary precision in the calculations that greatly increases the processing required, for example.

"Even if you use fewer bits, you can train a neural network to get the same results," says Avishek Biswas of the Massachusetts Institute of Technology.

Many big tech companies are also developing specialised hardware for running AI. Nvidia, for instance, has produced a chip just for self-driving cars – although the latest version still uses 500 watts.

Google, meanwhile, has created what it calls tensor processing units, or TPUs, designed to run its TensorFlow machine-learning framework, and is renting them out via the cloud.

There are more revolutionary designs in the works, too. Shunting data back and forth between the memory and processor wastes a great of deal of energy, says Biswas. So he has developed a chip intended for smartphones that slashes energy use by around 95 per cent by carrying out key operations in the memory itself.

CHRISTIE HEMM KLOK / NEW YORK TIMES/REDUX/EYEVINE

AI is used in cars, smart speakers and for playing games

LEE JIN-MAN/AP/REX/SHUTTERSTOCK

The pace of progress is astonishing. The latest version of AlphaGo, called AlphaGo Zero, runs on just four TPUs, and consumes around 400 watts.

But will these new chips actually bring down the overall energy use of AI? As AI becomes more energy efficient, we will build better systems and use it to do more, meaning there may be no net gain. "Certainly energy use will keep on going up with more sophisticated AI," says Welling.

In fact, AI is set to play a major part in the world economy. Global spending on AI systems is forecast to reach $60 billion in 2021, according to market research company IDC. Meanwhile, another research company, Gartner, predicts that

$4 trillion

Forecast value of AI-derived business in 2022

the value of AI-derived business will reach up to $4 trillion by 2022.

But we have no idea what this means for global energy use. It is estimated that computing and the internet use about 5 per cent of electricity globally, and AI is clearly a fraction of this at the moment.

"Not much is known about it at this stage," says Anders Andrae of Huawei Technologies, who studies the energy consumption of information technology. "But it is very dangerous to say that this is nothing to care about."

That's because what matters is not just how much energy AI itself uses, but also the knock-on effects. To go back to the example of self-driving cars, in theory they could operate in a way that reduces overall energy use despite their higher energy requirements. For instance, they could line up behind each other to reduce drag and communicate with each other so they don't need to stop at intersections.

But most of these savings require a high proportion of the cars on the roads to be autonomous – just as a social network like Facebook

5 per cent

The estimated fraction of global electricity used by computing

MICHAEL LECKIE FOR THE TIMES T2

can only really take off once it reaches a critical mass of people. "The network-dependent effects won't happen in the early phases," says Zia Wadud at the University of Leeds, UK, who studies transport and energy.

People with self-driving cars are likely to commute longer distances, because they won't need to focus on the road and can use the time for browsing the internet or watching videos. Wadud thinks this could double energy use – and his study doesn't count the AI part, or the massive increase in data traffic these vehicles are expected to generate.

In recent years, electricity demand has remained flat despite soaring internet traffic, thanks to big improvements in efficiency. But Andrae thinks we have reached the limits of the easy gains in efficiency.

If the amount of data we generate rises without big efficiency gains, information and communication technology energy use could soar to 20 per cent of all electricity by 2025 and account for a 20th of all carbon

"Energy use will keep going up as we develop more sophisticated artificial intelligence"

emissions, Andrae warns. "This could be a very huge problem," he says.

High costs make this worst-case scenario unlikely. But Andrae's work didn't factor in AI and could even be underestimating data growth, for instance from lots of AI cars talking to each other.

"I think AI will generate even more data than we have seen," he says. "If more data means money, they will use artificial intelligence to make more data, and more data means more electricity." And until our electricity systems are 100 per cent renewable, more electricity means more global warming. ■

For more on powerful computers, see page 42

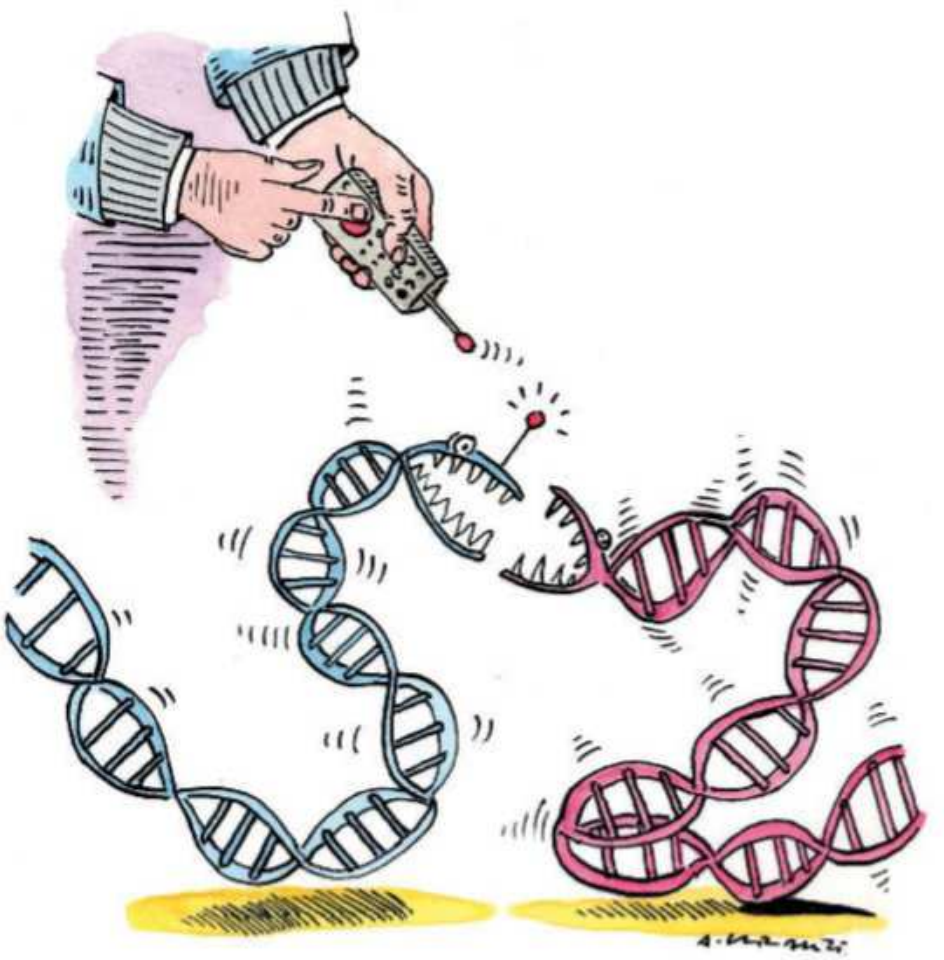
Remote control

The power to eliminate wild species using a "gene drive" needs to be curbed, say **Simon Terry** and **Stephanie Howard**

THANKS to a form of genetic engineering technology known as a gene drive, it is now possible to modify or even eliminate a wild species in its natural habitat, bypassing the laws of inheritance that have governed nature for millennia. The power to deliver "extinction to order" is potentially immense – as is the political challenge.

The technology works by driving a gene throughout a population, meaning the plants or animals containing the drives could impact ecosystems that cross not just country borders, but entire continents. And so far, there is no such thing as a safe gene drive or a reliable way to rein one in after release.

A number of authoritative bodies, including the US National Academy of Sciences, have called for international governance of the technology. In a recent study,



the Sustainability Council of New Zealand, where we work, suggested that countries proposing a gene-drive trial or release must first gain the consent of each country that could be affected, a process we call "collective consent".

This requirement is based on the principle at the core of the international biosafety protocol established through the United Nations. It says that countries importing living, genetically modified organisms have the right to prior, informed consent.

But consent is not enough. Uncertainty abounds where gene drives are concerned, so it is essential to apply the precautionary principle when undertaking risk assessment and to evaluate gene-drive proposals against alternatives that could achieve the same goal.

Methods of curbing the potency of this new technology have been

Political science

US conservatives are gearing up for an assault on reproductive rights, says **Lara Williams**

THE Trump administration has launched a review of state-funded research that uses fetal tissue, prompting many to speculate it is the start of a fresh battle on abortion rights in the US.

The Department of Health and Human Services (HHS) has announced that it is cancelling a contract for Advanced Bioscience Resources to supply the Food and Drug Administration (FDA) with fetal tissue for research purposes.

"HHS was not sufficiently assured that the contract included the appropriate protections applicable to fetal tissue research or met all other procurement requirements," the department said in a statement.

This was followed by the announcement of a full audit on the use of such tissue.

In the US, $98 million in grants, contracts and other state spending was dedicated to fetal tissue research just last year. It has been instrumental in developing vaccines and in fighting diseases such as Zika. Even so, research using embryonic stem cells and fetal tissues is heavily policed: several states, such as South Dakota and Florida, prohibit the use of such cells in research, and there are staunch restrictions on profiting from their supply. The HHS now suggests these controls are inadequate.

"The move is a troubling one from an administration headed by 'the most pro-life president in history'"

The move is a troubling one from an administration headed by "the most pro-life president in modern history", in the words of one supporter. Trump has stocked the HHS with anti-abortion advocates, with evident results: in October 2017, the HHS released a strategic plan that declared its purpose as "protecting Americans at every stage of life, beginning at conception".

And the cancellation of the HHS contract came soon after

proposed, such as trying to reduce the lifespan and geographic spread of a gene drive, but none has yet been demonstrated and all carry similar risks.

A failure to insist on proper governance invites a Wild West of unilateral actions without proper consideration of risks, alternatives and the consequences for other countries.

The UN Convention on Biological Diversity could be adapted to deliver what is needed. It is the most suitable structure currently available on which to build gene-drive governance. And until that is completed, international agreement is needed that no outdoor trials or releases will take place.

However we do it, there is no time to waste. Just three years after a gene drive was first proposed, scientists are hailing significant progress in gene drives for mosquitoes and mice.

In November, when the UN convention parties meet in Egypt, the international community has an opportunity to lay the groundwork to govern gene drives. It should not let this opportunity pass. ■

Simon Terry and **Stephanie Howard** work for the Sustainability Council of New Zealand

85 members of the House of Representatives sent a letter to FDA commissioner Scott Gottlieb, declaring that the "practice of conducting research using the body parts of children whose lives have been violently ended by abortion is abhorrent". This leaves little doubt as to the true motives underlying the audit.

This is more than an audit on scientific research, this is a deeply ideological gambit, opening the door for a further debate on women's agency and bodily autonomy. ■

Lara Williams is a writer based in Manchester, UK

ANALYSIS Global warming

BERTHOLD STEINHILBER/LAIF / EYEVINE

Wind power's warming effect is overblown

Michael Le Page

A STUDY has claimed that if the US generated enough electricity from wind to meet its current demand, the surface of the continental states would warm by 0.24°C. What's more, it goes on to compare this increase with global warming (*Joule*, doi.org/cvjz).

"Large-scale US wind power would cause a warming effect that would take roughly a century to offset," claims the headline on a press release issued alongside the study, implying that the savings in greenhouse gas emissions wouldn't counteract the warming for 100 years. Other climate scientists say this particular claim is misleading.

For starters, the study assumes a scenario where a third of the US is covered in wind turbines, says wind energy researcher Cristina Archer of the University of Delaware.

"That means you jump in your car in Ohio and drive all the way to the Rocky Mountains, and all you see at every point is wind turbines," she says. "It's a crazy scenario that's never going to happen."

What's more, the study relied on a regional climate model called the WRF. This model has a known flaw that exaggerates the air-mixing effect of wind turbines two or times, says Archer.

Then there's the comparison with global warming. The crucial point here is that wind turbines simply redistribute heat that is already in the air. At night, for instance, the ground cools and so does the layer of air just above it. The turning of turbine blades heats the surface by bringing down warmer air from above – the overall heat content of the atmosphere does not change and the effect ceases when the turbines stop turning.

"It gives such a bad reputation to wind if you start publishing this kind of stuff"

By contrast, higher levels of carbon dioxide trap heat, increasing the total heat content of the atmosphere and ocean. This effect lasts for millennia because extra CO_2 persists in the atmosphere for that long.

To put this another way, even if this study was right about the magnitude of the effect, and every inch of land in the world was covered with wind turbines, it wouldn't cause any melting of the polar ice caps.

The impact of wind farms has to be considered in the context of all the other changes we are making to the world. The urban heat island effect can warm cities by as much as 12°C compared with surrounding areas, but has a negligible effect on global temperatures. Buildings affect wind too.

Some of these points are stated in the paper, but they are buried two-thirds of the way through it. They are not made clear in the press release.

Asked whether the headline of the press release might cause misleading coverage, co-author David Keith of Harvard University replied: "I expect so. People will seize on all sorts of stuffs and exaggerate it."

Keith is not doubting the need to move away from fossil fuels. "There is no question that wind is better than coal," he says, but he is concerned about the impact of large-scale wind generation.

Archer thinks researchers should stick to analysing realistic scenarios for wind power. "It gives such a bad reputation to wind if you start publishing this kind of stuff," she says. "People don't see that it's a crazy scenario, all they remember is, oh, there's global warming from wind power." Except there isn't, of course. ■

Fossil futures

THE lasting geological impact of our species is clearly visible within the galleries of this potash mine in Russia's Ural mountains. The Urals contain one of the largest deposits in the world of this salt, one of the most widely used fertilisers. Mining has left behind vast subterranean galleries, their walls machine-carved with enormous ammonite-like whorls.

The Canadian photographer and artist Edward Burtynsky took this photograph for The Anthropocene Project, a collaborative chronicle of geologically significant human activity such as extraction, urbanisation and deforestation. Works from the project are on display at the Art Gallery of Ontario and the National Gallery of Canada, while this image and other photographs feature in Burtynsky's exhibition The Human Signature, at London's Flowers Gallery, to 24 November.

This September also saw the release of a documentary film, *Anthropocene: The human epoch,* and a book of colour photographs by Burtynsky, which includes new writing from author and poet Margaret Atwood.

Through publications, films and immersive media, Burtynksy and his Anthropocene Project collaborators – filmmakers Jennifer Baichwal and Nicholas de Pencier – convey the unsettling visual reality of resource depletion and extinction: how our planet's surface is being scarred, ground and shovelled into abstract, almost painterly forms.

The effects of mining, in particular, are irreversible. While animal burrows reach a few metres at most, humans carve out networks that can descend several kilometres, below the reach of erosion. They are likely to survive, at least in trace form, for millions or even billions of years.

There is an eerie poetry to this: burrows found in 500-million-year-old sediment tipped off geologists to the massive diversification of animal forms known as the Cambrian explosion. Will our own gargantuan earthworks commemorate more than just a mass extinction event? Simon Ings

Photographer

The future: lower carbon products

Reducing greenhouse emissions requires innovative advances, such as jet fuel made from used cooking oil and concrete that absorbs carbon dioxide as it hardens

When it comes to greenhouse gas emissions, it's easy to focus on coal-fired power plants and internal combustion engines. But another major source is less well known: the manufacture of cement and concrete.

"The cement manufacturers are the second largest emitters of carbon dioxide in the world," says Tom Schuler, president and CEO of Solidia Technologies in Piscataway, New Jersey. "They produce 5 to 7 per cent of all the man-made carbon dioxide that's emitted."

That is partly due to the sheer scale of the industry, says Schuler. "Concrete is the most used material on the planet after water." And the chemical processes involved in making cement and concrete have always emitted carbon dioxide. Now Solidia has a way to rein that in.

Cement is essentially made of calcium and silica, generally in the form of limestone and sand respectively. Cement manufacturers mix two parts limestone and one part sand, then heat the mixture in a kiln at 1500°C, transforming it into cement. The method has barely changed since the 1840s, when Joseph Aspdin and his son William developed and patented Portland cement.

This process produces carbon dioxide in two ways. The first is in heating the kiln, usually through burning fossil fuels. The second is the ensuing chemical reaction, which breaks down the limestone and liberates carbon dioxide.

Solidia has a new approach that releases far less carbon dioxide. It uses the same raw materials in a 50:50 blend, heated to a lower temperature of about 1200°C. This cuts both sources of carbon dioxide: it uses less limestone and less fossil fuel.

There is another advantage, too. Cement is usually mixed with sand, water and aggregate – rock fragments – to make concrete for construction. The water reacts with the cement, causing it to harden in a process called curing.

Solidia Cement™ cures in a different way: by reacting with carbon dioxide that is pumped in. "You'll actually see the [concrete] pick up about 5 per cent weight and that's the carbon dioxide converting to, essentially, limestone," says Schuler.

This is part of a small but growing effort to capture and use carbon emissions. To that end, Solidia wants to locate its plants wherever carbon dioxide is readily available. "It may be more cost-effective to put a concrete plant next to a source," says Schuler. One potential source would be an oil refinery.

That's one reason BP has invested in Solidia Technologies. Solidia has also been included in BP's Advancing Low Carbon accreditation programme that is helping to drive low carbon thinking across the company.

For now, Solidia is focused on getting its cement and concrete used by major manufacturers. To encourage uptake, the Solidia process is designed to be as similar as possible to existing practice so that manufacturers can use their existing equipment and raw materials.

Ultimately, Solidia wants to help address climate change. "Our goal is to turn carbon dioxide from a problem into a solution," says Schuler. ■

More at: solidiatech.com and newscientist.com/BP

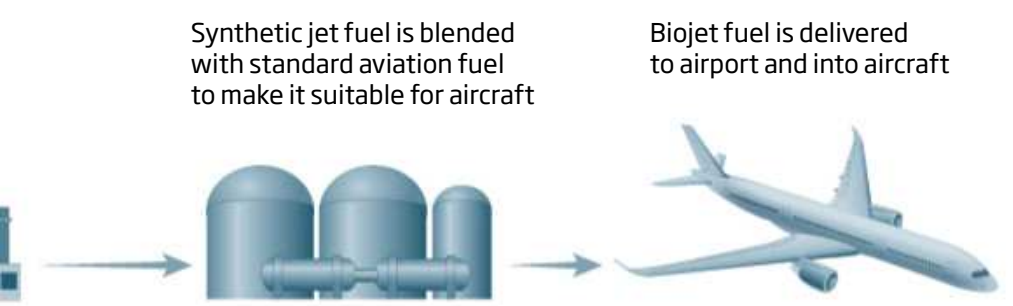
Information and views included in this article are those of the individuals providing them and do not necessarily reflect the opinion or views of BP plc or any member of the BP Group.

"Our goal is to turn carbon dioxide from a problem into a solution"

Oil aboard

Solidia Concrete™ absorbs carbon dioxide as it sets, says Tom Schuler

Biojet can be a lower carbon aviation fuel, says Tom Parsons



BP Biojet

Aviation is a significant source of greenhouse gases. "Today, it accounts for about 2 per cent of global emissions," says Tom Parsons, Biojet commercial development manager at Air BP. That is not a huge share but without improved efficiency, aviation emissions will continue to increase. "It will become 3 per cent by around 2050 if no action is taken."

The International Air Transport Association wants to halve aviation's net carbon dioxide emissions by 2050, relative to 2005 levels. But how? Cutting emissions from aeroplanes is difficult, compared with road and rail transport where options include electrification of vehicles, says Parsons. "You physically can't carry enough battery weight to make those planes fly, at this stage."

Instead, BP is focusing on how conventional aeroplane fuel – essentially high-grade petrol – can be replaced with a more sustainable equivalent. This is where the BP Biojet comes in.

Until recently, waste oil from restaurants was typically poured into landfill sites. There, it decays to produce methane – another greenhouse gas. That can have a negative impact on the environment. So BP is using this recycled oil in its new green aeroplane fuel.

First, tankers collect the used oil from restaurants for processing into fuel. "It's aggregated, it's cleaned up a bit, and then it goes into a specialist biorefinery," says Parsons. There it undergoes a chemical reaction with hydrogen to remove excess oxygen and to give it properties that make it practically indistinguishable from fossil jet fuel.

The new fuel can be carried in existing pipes and tankers, and pumped straight into planes. "You don't need to modify the planes," says Parsons. "Nothing needs to change."

Planes can't yet fly solely on Biojet because aviation fuel must contain a small amount of ring-shaped organic molecules called aromatics. So aviation biofuel has to be blended with ordinary fuel. "You can have a one-to-one ratio with conventional jet fuel," says Parsons.

BP already sells this blend to three airports in Norway and Sweden. When a person books a plane ticket from a company that uses BP Biojet, they may be offered the option to pay extra. If they opt in, the money is used to buy Biojet, although their flight might not be one that uses it. In practice, planes tend to fly with a small percentage of aviation biofuel.

Even that makes an important contribution. BP Biojet reduces greenhouse gas emissions compared with standard fossil jet fuel, one of the key reasons it has been accredited by BP's Advancing Low Carbon programme.

However, used cooking oil will never supply enough fuel for all the world's planes. So BP is looking for other sources of low carbon feedstock.

For instance, Parsons says, it could be possible to make fuel from household solid waste. "There's even potential to convert excess renewable energy into liquid fuels," he says.

No single technology will be enough to slash aviation emissions, Parsons emphasises. "We're going to need everything."

The ghosts within

Hidden within our genomes are traces of completely unknown species. **Catherine Brahic** investigates

PETER STRAIN

WE LEARN about our ancestors in many ways. Bones tell us what they looked like. Teeth reveal their diet. Tools, pots, art and other artefacts hold stories about their culture. Then, a decade ago, the first ancient genome was sequenced, opening a whole new window on our past – one that promised more intimate insights.

The breakthrough famously revealed that Neanderthals got very cosy with humans. Since then, geneticists have been probing more and more fossils for evidence of past cross-species dalliances. The studies haven't disappointed. But in an intriguing twist, they have started to kick up something unexpected: hidden inside genomes are signs of ancestors that we never knew existed. Geneticists call them "ghosts".

We have no physical record of these ancient hominins – no bones, no tools, no archaeological remains whatsoever. Yet the genetic code that they left within fossils of other hominins, and in living humans too, is offering profound and unprecedented insights into how our species came to be, and what the world was like at the time.

The idea that each of our cells might contain fragments of genetic code from extinct species has been around for well over a decade. Then, in 2008, Svante Pääbo and his team at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, pulled off the master stroke of teasing DNA out of millennia-old Neanderthal bones in quantities great enough to sequence. This provided an obvious way to find out if *Homo sapiens* had bred with Neanderthals (*Homo neanderthalensis*): you could simply look within the genomes of living people for DNA sequences with distinctly Neanderthal patterns of mutations. These comparative studies revealed that early humans had indeed mated with Neanderthals, and not just once. Current estimates are that the genomes of everyone except Africans are between 2 and 4 per cent Neanderthal.

Unexpected dalliances

Here were two clearly distinct species, separated by up to 700,000 years of evolution, yet the remnants of their sexual proclivities are captured in the DNA of the majority of people alive today. What's more, it soon emerged that our ancestors weren't only getting it on with Neanderthals.

Just as Pääbo was finishing sequencing the Neanderthal genome, a parcel landed on his desk. It contained a tiny fragment of a finger bone from the Altai mountains in Siberia. The piece was 30,000 to 50,000 years old and was thought to be from another Neanderthal. His team was in for a big surprise. The DNA analysis revealed an entirely new group of archaic humans, now dubbed the Denisovans, which split from a common ancestor with Neanderthals some 500,000 years ago.

Once again, comparisons with modern human genomes showed that the two interbred. Genetic studies reveal this to have happened in Eurasia. They also show that Denisovans ranged from Siberia to South-East

Asia, and that at least one of their genes helps modern Tibetans to live at high altitude. The idea that our ancestors hybridised with other hominins was once dismissed. Now it was starting to look as though they would mate with anything vaguely human.

Denisovans are nearly ghosts: we have that one finger bone and a few molars as a physical testament to their existence, but no more. Then in 2016, a true ghost emerged from the genomes of 44 individuals who lived in the Middle East between 14,000 and 3400 years ago. Their DNA held genetic markers indicative of a distinct group of ancient *H. sapiens* based in the region more than 45,000 years ago. The members of this population are now known as Basal Eurasians, and they present a conundrum. Their DNA, which is still found in modern Europeans, shows none of the telltale signs of interbreeding with Neanderthals. This came as a surprise because ancestral humans mated with Neanderthals very soon after leaving Africa 60,000 years ago in the migration that was to give rise to all people of non-African heritage alive today.

The most-likely explanation is that soon after that migration, a group of humans became isolated while the rest bumped into and mated with Neanderthals. "If you like, it's a third branch," says Chris Stringer of the Natural History Museum in London – a branch that is distinct from the humans who had stayed in Africa and the ones who were gradually spreading out across Eurasia, Australia and eventually into the Americas. ›

ANIMALS HAVE GHOSTS TOO

At a conference in China earlier this year, Tomas Marques-Bonet flashed up a slide showing an evolutionary tree of chimpanzees and bonobos. Off to the right of the longest branch was a cartoon Pac-Man-style ghost, with its hands up in the air.

Marques-Bonet and his colleague Martin Kuhlwilm, both at Pompeu Fabra University in Spain, had been looking at the genomes of wild chimps and bonobos in central Africa when they found odd fragments of DNA. The fragments couldn't be explained by ancient matings with each other, or by random mutations. The DNA, they say, comes from an unknown or "ghost" bonobo population that must have become isolated, evolved independently and later mixed back in with its long-lost relatives.

At the same conference, Greger Larson at the University of Oxford revealed the results of a study of the origins of domesticated dogs in the Americas. Through genetic analyses, his group had traced the ancestry of a mysterious population of dogs that arrived in the New World around 11,000 years ago. The dogs, Larson said, probably accompanied a second wave of human migrations over the land bridge from Siberia and then spread across the continent. They were entirely replaced when European settlers brought their dogs with them.

However, traces of the original American canines live on in a rather strange place. Canine transmissible venereal tumour is described as the world's worst STD. Genetic analyses of these tumours, found on dog genitals, revealed that they are more closely related to the first American dogs than to any alive today.

Because there are no known fossils belonging to Basal Eurasians, it is impossible – for now – to say why they were isolated. Perhaps it was just down to where they settled, far from other groups. Or maybe they developed cultural differences. Either way, these ghosts didn't mix with the rest of humanity for millennia – long enough to evolve distinct genetic markers.

The Basal Eurasian research showed that rich insights into human history can be gleaned from DNA alone. But, like the Neanderthal and Denisovan studies, it relied on obtaining DNA from fossils, something that remains a huge challenge. DNA degrades with time, so it takes special fossils and special skills to extract it from very old bones, particularly ones that have spent thousands of years buried in hot climates. However, in the mid-2000s, geneticists were already discussing another approach. Among others, Jeffrey Wall, now at the University of California, Los Angeles, and Vincent Plagnol, now at University College London, suggested that it might be possible to spot signs of extinct populations in the DNA of modern humans, simply by using clever statistics.

The broad idea is that all DNA is subject to random mutations that accumulate over millennia and are passed down from generation to generation. By looking at mutation patterns in modern populations, it is possible to spot segments that don't match the usual *H. sapiens* pattern. These are presumed to come from populations that evolved separately from our own species for thousands of years before mating with humans. Statistical modelling can then produce estimates of when the two groups mated and how different the other population was from our ancestors.

The past few years have seen several attempts to refine these methods and apply them to Africa – the birthplace of our species and the setting for a slice of our history that we know very little about. This new research has revealed the presence of at least one ancient ghost on the continent.

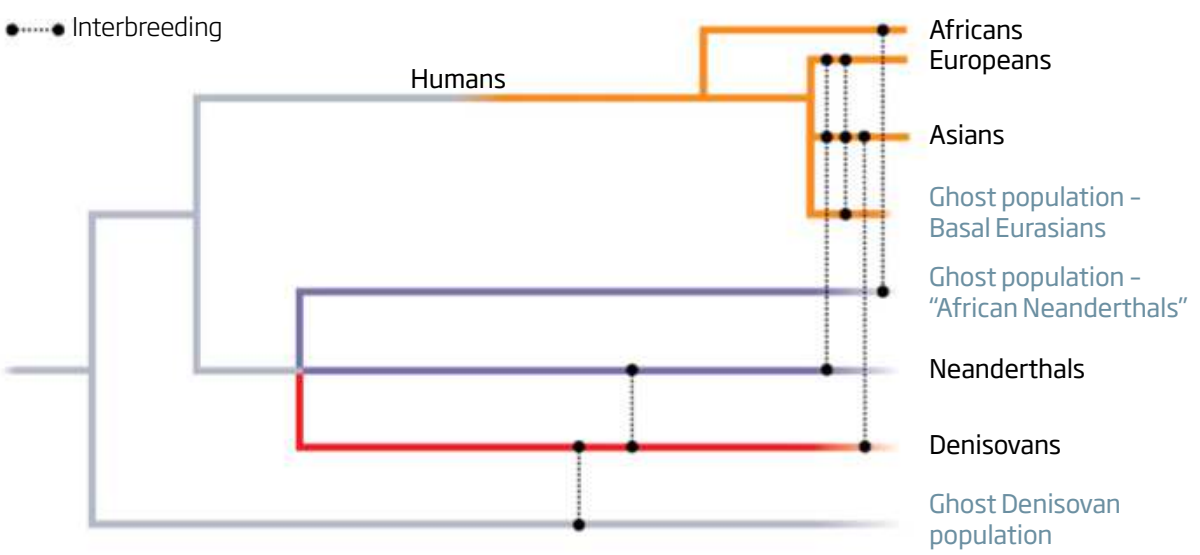
African Neanderthals?

Josh Akey at the University of Washington in Seattle, Sarah Tishkoff at the University of Pennsylvania and others have spent years sequencing and analysing the genomes of modern Africans who belong to groups with deep ancestral roots, including the Baka hunter-gatherers from Cameroon, and the Hadza and Sandawe from Tanzania. Within these genomes, they have found stretches of DNA that appear to come from another hominin species. Because this DNA is found only in the descendants of African people – not in any Eurasians – the ghost species must have interbred with *H. sapiens* after the out-of-Africa migration 60,000 years ago. In fact, by the team's calculations, this probably happened within the past 30,000 years. If true, this is huge. It means that until very recently, there was at least one other species of hominin living alongside us in Africa. According to Akey, soon-to-be published evidence suggests there might have been more than one.

The African ghosts appear as evolutionarily distinct from modern humans as Neanderthals and Denisovans are. "What that means is that they probably came from the same

Mystery ancestors

Genetic analysis has revealed that our family tree contains at least three ghosts: species or populations for which we have no evidence except for their DNA



African population that Neanderthals trace their ancestry to," says Akey. "So the idea is that 700,000 years ago, there's a population in Africa that splits off from the modern human lineage, goes out of Africa and becomes what we recognise as Neanderthals. At the same time, there's another split in Africa that becomes sort of like an African Neanderthal."

Who these "African Neanderthals" were is a mystery. One clue could come from a fossil that Stringer worked on for his PhD back in the 1970s: the Iwo Eleru skull from Nigeria. At around 13,000 years old, this individual was alive just a millennium or so before some humans first started farming, yet it has a strange mix of modern and primitive features. Recently, Stringer and Katarina Harvati at the University of Tübingen in Germany did a fresh analysis of the skull. This confirmed that it is very odd for its age. "It actually resembles early *sapiens* fossils rather than late ones, and it certainly doesn't look like any recent Africans," says Stringer. "We suggested this could be an example of an African whose population had received this archaic introgression." In other words, it might be a human whose ancestors mated with an African ghost.

As yet, no ancient African hominin has had its genome sequenced, so it is possible that physical remains of this ghost have already been unearthed. One candidate is *Homo naledi*, a species discovered in 2013 deep inside a narrow cave system in South Africa. The fossils are around 250,000 years old, but no one knows how long the species survived. If pressed, however, Stringer would put his money on another suspect. "My bet is that *Homo heidelbergensis* is the introgressor," he says. Recent unpublished evidence suggests that this species was still around less than 300,000 years ago, when humans had already appeared. Alternatively, the ghosts may have been a subpopulation of *H. sapiens* that, like the Basal Eurasians, was isolated from other populations for long enough that its members' DNA acquired different markers. "It could be the case that 100,000 years ago or more, there are different populations of anatomically modern humans in different parts of Africa," says Tishkoff. "And maybe at some point they mix with each other and maybe some populations died out."

Tishkoff thinks it would be surprising if our ancestors didn't mate with other ancient hominins in Africa. However, she cautions that the evidence for African ghosts is still tentative: because we know so little about the

A mystery ancestor lives on in the DNA of the Baka people from Cameroon

MATTIAS KLUM/NATIONAL GEOGRAPHIC CREATIVE/GETTY

population history of Africa, she and her colleagues had to make many assumptions to interpret their data. "That doesn't mean [hybridisation] didn't occur in Africa," says Tishkoff. "It's likely to have occurred. It's just really challenging to prove." The clincher will come when someone is able to sequence DNA extracted from an African fossil and compare it with the fragments of ghost DNA found in modern Africans. That is a challenge, but, given the advances in ancient DNA sequencing in the past decade, it is probably only a matter of time before someone meets it.

> "There may have been a few hominin species living recently with us in Africa"

"Genetics in general is changing how we understand our species," says Tomas Marques-Bonet at Pompeu Fabra University in Spain. "To me, everything starts with Denisovans: the first time we lifted DNA from a finger and found neither human nor Neanderthal – something for which we have no face and very little other information – that was the first time genetics illuminated something that had totally escaped palaeontology."

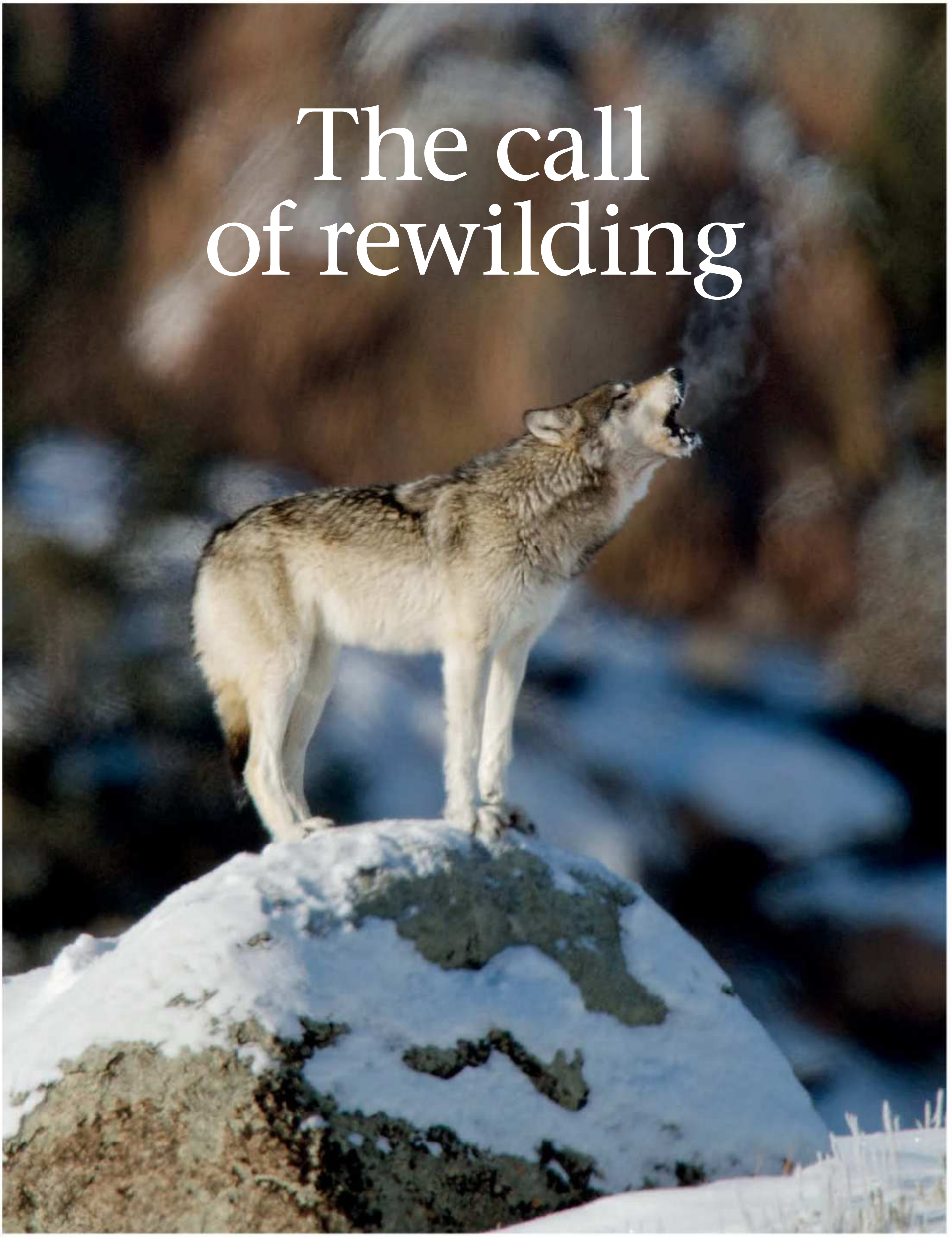
It now transpires that Denisovans had their own ghosts. People living in Oceania and East and South-East Asia today have inherited about 5 per cent of their DNA from Denisovans. By taking a closer look at these genetic sequences, Akey's team found that they don't all relate to the original finger-bone genome in the same way. In fact, the group found signs of two evolutionarily distinct Denisovan populations. "That was really unexpected," he says. "There's actually another, ghost, Denisovan lineage."

What all these studies highlight is that it was the rule, rather than the exception, for hominin populations to split for thousands or even hundreds of thousands of years and then meet again and mate. Neat, bifurcating evolutionary trees must be abandoned. "Take a pen on a piece of paper and start making squiggly lines," says Akey. "That's human history." On a more basic level, it is also causing many in the field to stop using the terms species and subspecies to refer to different hominins, preferring instead to talk about groups or populations. After all, individuals that belong to different species – like *H. sapiens* and *H. neanderthalensis* – aren't meant to be able to produce viable offspring.

Ghosts and nearly-ghosts are making the ancient world a much less lonely place. "If we look around the world today, we are really the only hominin game in town," says Akey. "People assume that's the way it must have always been. In fact, the world was a much more interesting place not that long ago." ■

Catherine Brahic wrote this while at *New Scientist*. She now works at *The Economist*

The call of rewilding



BARRETT HEDGES/BEARHEAD PHOTOGRAPHY RIGHT: COURTESY OF KNEPP CASTLE ESTATE

The idea of letting nature reclaim land has swept the West. But does it work? **Graham Lawton** reports

"IT WAS a picture postcard of how the English countryside is meant to look," Isabella Tree tells me. "It was a working farm. We had green fields, manicured hedgerows and ditches, land that was constantly active with maize, barley, rye and grazing cattle. We didn't realise it at the time, but it was virtually a biological desert. Now it looks much more like Africa."

She's talking about her home, the Knepp estate in West Sussex. Seventeen years ago, she and her husband Charlie Burrell stopped trying to coax a living out of its heavy soil. Today, the 1400-hectare estate is the closest thing in southern England to a primaeval landscape: a mosaic of water meadows, thorny scrub, sallow groves and grazing lawns roamed by cattle, ponies, pigs and deer. "The colliding of different habitats has been rocket fuel for biodiversity," says Tree.

Knepp is an experiment in "rewilding", a movement that has swept the Western world in recent years. It takes different forms in different places, but a simple and compelling concept drives it: let nature run things and it can right the wrongs we have done Earth's wildlife. Habitats will restore themselves and biodiversity will bounce back, along with the vital services that the ecosystems provide, such as pollination and water purification.

Yet even as experiments like Knepp take off, researchers are voicing concerns about how effective rewilding truly is. Meanwhile, the world has embarked on a huge but largely undirected rewilding project as vast tracts of once-productive agricultural land are abandoned. This is bringing unexpected answers as to what really happens when you let nature run its course.

The original concept of rewilding is attributed to ecologist Michael Soulé at the University of California, Santa Cruz. In 1998, he published an essay outlining a new approach to conservation in North America. He advocated creating wildlife corridors between existing reserves, linking them up to create wildernesses large enough to support native carnivores such as wolves and bears, or even introduced ones such as lions.

The idea was underpinned by cutting-edge ecology, and specifically the concept of trophic cascades. This holds that ecosystems are principally shaped by the feeding behaviour of large herbivores and carnivores, the "apex consumers" largely absent from today's human-dominated ecosystems. Put them back in, so the logic went, and the ecosystem would automatically be restored to a healthier, more biodiverse state.

When Soulé proposed rewilding, the trophic cascade hypothesis was already being tested on the ground in Yellowstone National Park. The creation of the park in 1865 did not stop rangers from shooting wolves, the natural apex predators. By the 1920s, they had been totally eradicated, with huge knock-on effects.

Yellowstone National Park with its reintroduced wolves (left) and the Knepp estate in the UK (above) are rewilding showcases

The elk population exploded, causing bison to decline owing to competition for food, and beaver numbers to crash as elk overbrowsed trees next to rivers. Coyotes also boomed and gobbled up the pronghorn antelopes.

In 1995, after a long campaign, wolves were reintroduced to Yellowstone. Almost immediately, the changes went into reverse. Trophic cascades were elevated to an iron rule of ecology. Ecologists John Terborgh and James Estes described them in a 2010 book on the subject as a "universal property of ecosystem functioning, a law of nature as essential and fundamental to ecology as natural selection is to evolution".

Of the many big and charismatic rewilding projects that have now been set up, most are essentially attempts to restore trophic cascades by reintroducing large animals, with the hope they will force the ecosystem back to an earlier state. One of the oldest and most famous is Pleistocene Park, a 160-square-kilometre nature reserve just north of the Arctic circle in Siberia. Since 1996, scientists there have been attempting to recreate the "mammoth steppe" that circled the northern hemisphere at these latitudes at the end of the Pleistocene epoch 12,000 years ago.

Back then, most terrestrial ecosystems were dominated by huge herbivorous mammals such as mammoths, rhinos, mastodons and ground sloths. They ate, trampled and dug up vast amounts of vegetation, kept grasslands free from trees and recycled nutrients through their copious dung. When they were wiped out by human hunters, the ecosystem was pushed into a radically different state: less open, less fertile and less biodiverse. With the megaherbivores gone, predators such as lions, bears and wolves called the shots, keeping populations of smaller herbivores in check through their own trophic cascade – until the predators were themselves hunted almost to extinction.

These waves of losses happened across the world. Some 100 genera of megafauna died out, precipitating a wave of secondary extinctions. The result was an overall simplification of food webs, a process called trophic downgrading. According to a review paper published in *Science* by Estes, Soulé, Terborgh and others in 2011, "the loss of apex consumers is arguably humankind's most pervasive influence on the natural world".

But how do you make a mammoth steppe when mammoths have long since bitten the dust? This touches on one of the most troublesome questions in rewilding biology. Rewilding implies a return to a previous state, yet restoring things to the way they were before humans is often not an option. The original animals may be extinct, or the reintroduction of predators may provoke opposition from people worried about their own safety or that of their livestock.

In Pleistocene Park, the ecological role ›

of mammoths is taken by herds of animals including musk oxen, elk, yaks, Yakut horses, European bison and reindeer, predated upon by existing populations of bears and wolves. According to park manager Nikita Zimov of the North-East Scientific Station in Yakutia, that is bringing results. "I would not call it a steppe ecosystem at the moment, but we are going there," he says. "It is not an easy task to shift from one ecosystem to another." The park is more biodiverse and more productive than the tundra it has replaced, he says, with knock-on benefits for ecosystem services, especially carbon sequestration.

In North America, however, Soulé's original vision has been slow to materialise. An organisation called the Wildlands Network is gradually piecing together four separate wilderness areas across Canada, the US and Mexico, but progress is glacial. Soulé, now in his 80s, is philosophical. "Conservation is always an uphill battle," he says. "There are so many elements in society that don't want any sort of restoration to occur because it interferes with economic activity."

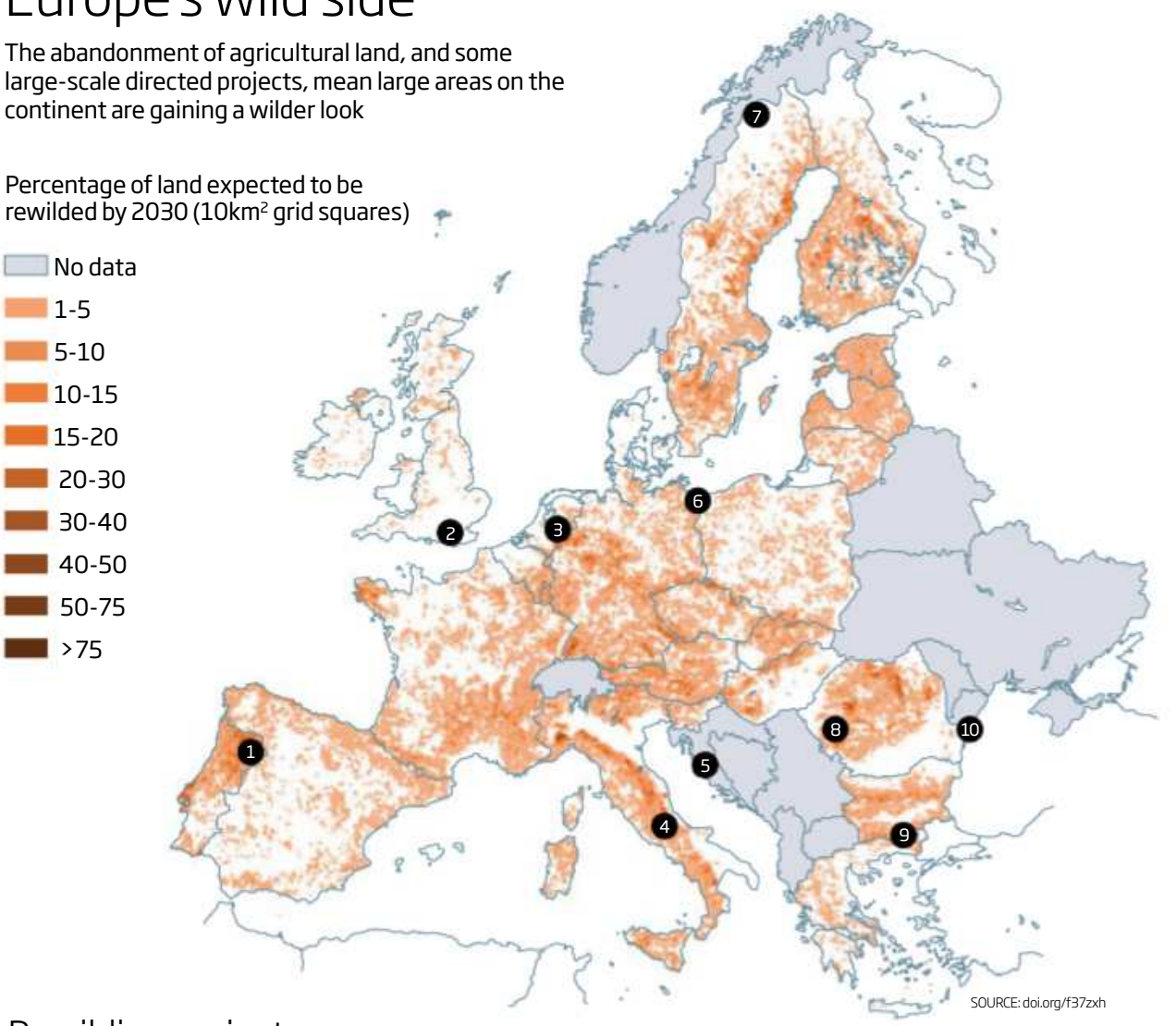
In parts of Europe, though, Soulé's ideas are alive and well, largely thanks to the fact that large predators are already making a comeback. This means trophic cascades can be restored simply by reintroducing herbivores, a "cannon fodder" approach that is the key to one of Europe's grandest rewilding projects, in the Rhodope mountains straddling the Bulgaria-Greece border. The idea here is to create corridors between the area's existing national parks to build a wilderness covering 2500 square kilometres, and to restore the deer population to provide food for the wolves and bears already living in the mountains.

Deli Saavedra of the NGO Rewilding Europe, which oversees the project, calls this trophic change restoration. "It is not about looking back, but looking forward," he says. "It is impossible to try to restore ecosystems to how they were, so we will end up with something new, but we still want them to be more natural – more wildlife, more natural

This is the third in Graham Lawton's series of articles on biodiversity across the globe. Send your suggestions for topics to cover to **biodiversity@newscientist.com**

Europe's wild side

The abandonment of agricultural land, and some large-scale directed projects, mean large areas on the continent are gaining a wilder look



SOURCE: doi.org/f37zxh

Rewilding projects

1 Western Iberia
Portugal

1000km²

Habitats: Old oak forests, steep river gorges, rocky heathland

Signature species: Iberian lynx, Iberian wolf, imperial eagle

2 Knepp, UK
(See main text)

3 Oostvaardersplassen
Netherlands

(See main text)

4 Central Apennines
Italy

1000km²

Ancient beech woods, open hillsides, alpine grasslands

Marsican brown bear, Apennine chamois

5 Velebit mountains
Croatia

2200km²

Mediterranean coastline, forests, deep canyons, alpine grasslands

Balke chamois, bear, wolf, lynx

6 Oder delta
Poland/Germany

2500km²

Wetlands, forests, grasslands, bogs, dunes, beaches, open sea

White-tailed eagle, beaver

7 Lapland
Sweden/Norway

35,000km²

Boreal forests, mountains, glaciers, rivers, wetlands

Moose, wolverine, reindeer

8 Southern Carpathians
Romania

1000km²

Old-growth forests, rivers, mountains

European bison, wolf, lynx, bear

9 Rhodope mountains
Bulgaria/Greece

2500km²

Oak and beech forests, grasslands, rivers, rocky slopes and cliffs

Black vulture, wolf, jackal

10 Danube delta
Romania

1800km²

Rivers, lakes, marshes, steppes, dunes, lagoons, salt marshes, forests

White-tailed eagle, pelican, jackal

SOURCE: REWILDINGEUROPE.COM

processes – where nature can manage itself."

The expectation is that deer and wolves will eventually recover to their natural population densities, and black vultures will follow thanks to the carcasses left after wolf kills. With plenty of deer to eat, the wolves should also be less likely to attack livestock, so human-wildlife conflict will be reduced. "We're now seeing results, with much higher densities of deer impacting the wolves and vultures," says Saavedra.

Full trophic restoration of this kind requires vast areas for predators to roam – a wolf pack typically needs around 200 square kilometres. In landscapes fragmented by human activity, such as those of Europe and North America, this is rarely an option.

The answer can be to go halfway, restoring the herbivores, but leaving out the carnivores. This is the approach taken at Knepp, in England's densely populated south, and at another well-known rewilding project, Oostvaardersplassen in the Netherlands. This 56-square-kilometre site east of Amsterdam was reclaimed from the sea in 1967 and earmarked for industrial development. Nothing happened and it gradually ran wild, becoming an important bird habitat.

To keep this habitat from being swallowed by forest, in the early 1980s its managers introduced cattle and horses to intensify the grazing. Red deer were added in 1992. Their activities have helped to create an ecosystem that ecologist Frans Vera, the site's manager, has claimed is analogous to late Pleistocene Europe. But the lack of carnivores to devour the herbivores, and provide a natural brake on the amount they consume, means they must be culled or given supplementary food from time to time. Similarly at Knepp, some of the grazers are culled periodically and their meat sold, meaning humans are effectively acting as apex predators.

That raises questions as to whether such projects are true to the spirit of rewilding. But the concept of trophic cascades has itself recently come in for criticism. "Why do we assume that all ecosystems in the world are controlled from the top?" asks David Nogués-Bravo at the University of Copenhagen in Denmark. "This is one of the main scientific assumptions in rewilding, but there are many exceptions."

He points to recently published research digging deep into the causes of ecological change at the end of the Pleistocene at five sites in Britain and Ireland. This concluded that climate was much more influential than the presence or absence of megaherbivores.

BABAK TAFRESHI/NATIONAL GEOGRAPHIC CREATIVE

UTRECHT ROBIN/ACTION PRESS/REX/SHUTTERSTOCK

Rewilding landscapes: Portugal's Côa valley (above), and Oostvaardersplassen in the Netherlands (left)

200 km²

The space a wolf pack typically needs to roam in

Even in Yellowstone, the quintessential example, the strength of the trophic cascade effect has been questioned. "It's safe to say that, generally, wolves reduce their prey populations and that has varying effects on the vegetation that prey feed on," says L. David Mech of the Northern Prairie Wildlife Research Center in North Dakota. "But below that trophic level, effects are more diluted and variable." The increase in beaver numbers following the reintroduction of wolves, for example, probably had less to do with the end of elk overgrazing and more to do with a separate programme to bring back beavers that took place soon after the wolves were returned.

Another sceptic is Richard Corlett at the Chinese Academy of Sciences' Center for Integrative Conservation in Yunnan. He says that rewilding programmes have got ahead of the science and there is an urgent need for long-term experiments. "I'm a general supporter of rewilding," he says. "The romantic aspect appeals to anyone involved in ecology who has seen everything go downhill in the past 50 years. But the lack of science is a major issue."

Despite these concerns, rewilding is becoming a fixture of conservation biology. Most of it is happening entirely by accident, however, as huge swathes of farmland are taken out of productive use.

According to some estimates, within the European Union alone about 300,000 square kilometres of farmland will be abandoned between 2000 and 2030, an area about the size of Italy. Abandonment is also happening in the Americas, Australia and some developing countries, driven by low productivity, agricultural intensification and demographic change. Much abandoned land is in marginal areas such as uplands. Once deserted, most is simply left to its own devices.

This is known as passive rewilding. It may not get pulses racing in the same way as releasing charismatic mammals into a wilderness landscape, but in terms of land area it is much more significant. "That is the future of rewilding," says Corlett. "If you look at the estimates of land likely to be abandoned, they are as big as current protected areas and much bigger than classic ecological restoration projects." That is a huge opportunity to revive biodiversity, ›

Herds of longhorn cattle and wild pigs manage the Knepp estate ecosystem

DAVID WOODFALL

COURTESY OF KNEPP CASTLE ESTATE

but it needs to be supported by good science. "We need to know what happens when we just abandon land," says Corlett.

There are some indications. In 2014, a team led by Cibele Queiroz of the Stockholm Resilience Centre in Sweden reviewed 276 studies on the effect of farmland abandonment. Surprisingly, the researchers found that while some areas saw an increase in biodiversity, most did not, especially in Europe.

That is because traditionally farmed landscapes often create a wide range of habitats for wildlife. When human intervention stops, these biodiverse "cultural landscapes" disappear.

A classic example is Portugal's Côa valley, which has one of the highest levels of land abandonment in Europe. The area was once used for grazing cattle and running pigs, and also produced cork, honey, firewood and wild foods such as mushrooms. This low-intensity agriculture created a mosaic of habitats with high levels of biodiversity, supporting endangered Iberian lynx and Spanish imperial eagles. But as abandonment progresses, much of the Côa valley has become choked with dense scrub and forest, and is under constant threat of wildfires.

It is a similar story in Japan. There, traditional terraced rice paddies are rapidly being deserted as the population dwindles and people switch from rice to wheat. Since 1961, half of the land once turned over to rice, amounting to around 2700 square kilometres, has been left to run wild. Another 1600 square kilometres is expected to follow in the next decade. Management of the paddies, through flooding and mowing, maintains a diversity of habitats and wildlife. When it ceases, the fields become choked with vines and invasive bamboos. Over the past 15 years, Japanese ecologists have documented a steady decline of insects, birds, amphibians and plants.

"Passive rewilding is not problem-free," says Corlett. "You don't get an original, native ecosystem. You tend to get dominated by invasive species and you lose species that have adapted to human-made habitats."

For some of these areas, a certain amount of active rewilding may be the answer, as at Knepp, where species surveys show that the activity of herbivores has driven an increase in biodiversity. The Côa valley is one of Rewilding Europe's flagship projects. It plans to reopen the landscape by introducing horses and cattle. But given the scale of land abandonment, such active, well-planned intervention will remain a rare luxury.

To find out more about the effects of passive rewilding, I visited a nature reserve in the uplands of northern England, where experiments have been going on for more than 60 years. Moor House-Upper Teesdale National Nature Reserve was established in 1952. A vast area of bleak and soggy moorland, criss-crossed by streams and scarred by the remains of 19th-century lead mines, it represents exactly the sort of hardscrabble land where passive rewilding will mostly happen. "There's a large proportion of land that is very marginal for agriculture, and it's likely to be this marginal land that goes out of production," says my host at the site, Rob Rose of the Centre for Ecology and Hydrology in Lancaster.

Starting in 1953, scientists began fencing off areas to see what happens when they are left ungrazed by sheep. In total, eight areas were enclosed and have now been undisturbed for 50 years or more. This experiment has been particularly relevant to the rewilding debate in northern Europe, Rose tells me. For example, a common view of the British uplands, promoted by the writer and activist George Monbiot and others, holds that the Lake District National Park, a little to the west of Moor House, is a biodiversity desert destroyed by overgrazing, and that the answer is to take sheep off the land.

We trek over to an enclosed plot called Bog Hill. Sheep have been excluded from this mossy mire for 65 years, but to the naked eye, the land inside and outside the enclosure is identical. Detailed studies of the soil and vegetation confirm that very little has changed. The story is repeated at all the plots. "A lot of the landscapes here are very resilient to change," says Rose.

This suggests that bringing back nature by doing nothing can take an awfully long time, and taking the sheep away from areas such as the Lake District will do little or nothing for biodiversity. Perhaps the reverse: at Knepp, they kept one plot out of bounds to the big animals and did not see the same explosive rebound of nature, says Tree. "Without the heavy-hitting herbivores, the land takes ages to move," she says.

In many places, then, passive rewilding looks to be an oxymoron. Just leaving land to go its own way may actually lead to a further reduction in biodiversity, not an increase. For that reason, Corlett advocates active intervention, at least in the beginning. "We have to work out something cheap to do on abandoned land that enhances conservation. I suspect it will turn out to be some selective reintroductions," he says.

If we do work it out, abandoned farmland represents our best chance yet of substantially rewilding large areas. Despite the challenges ahead, Tree is optimistic. She says that Knepp is the start of something bigger, something not dissimilar to Soulé's vision of joining up existing reserves to create vast areas.

"Farmers now, at least on marginal land like ours, are considering joining forces and becoming farm clusters, pulling up their borders and doing projects like this," says Tree. "We need more space for nature. Rewilding can provide the webbing to link the isolated spots and connect up the bigger landscape. We're very excited." ■

300,000 km²

Estimated farmland area to be abandoned in the EU between 2000 and 2030

Graham Lawton is a feature writer for *New Scientist*

DUKE DOWNEY/POLARIS/EYEVINE

Philip Zimbardo in 1971. He is now 85 and still gives talks

The evil inside us all

Philip Zimbardo's Stanford prison experiment was one of the most seductive pieces of drama in the history of psychology, despite its flaws. **Gina Perry** explores what makes it so compelling

IN A darkened auditorium in September 2008, I sat in the audience awaiting the start of a presentation entitled "The psychology of evil" by social psychologist Philip Zimbardo. Suddenly, the doors at the back of the theatre burst open, lights flashed and Santana's song *Evil Ways* blared from the speakers. A man with slicked-back black hair and a devilish pointy beard danced up the aisle towards the stage, snapping his fingers in time with the music. Zimbardo's flamboyant entrance was startling, given the nature of the talk.

I shouldn't have been surprised. Zimbardo's knack for performance is one of the reasons his Stanford prison experiment is one of the most famous psychological studies of the 20th century, alongside research into obedience carried out by his high-school classmate, Stanley Milgram.

Eschewing conventional academic reporting, Zimbardo's first account of the experiment was a sensational piece that appeared in a supplement of *The New York Times*, showcasing his skill as a storyteller. The article kicked off by detailing how, one sunny morning in Palo Alto, California, in 1971, police swooped on the homes of nine young men. They were bundled into squad cars, taken to the police station, charged, then blindfolded and transported to the Stanford County Jail, where they met their guards.

The "jail" was actually a set-up in the basement of a building at Stanford University. The prisoners were one half of a group of volunteers, the other half being assigned the role of guards. In what Zimbardo described as "a gradual Kafkaesque metamorphosis of good into evil", these seemingly well-adjusted ›

young men became increasingly brutal as guards. They "repeatedly stripped their prisoners naked, hooded them, chained them, denied them food or bedding privileges, put them into solitary confinement, and made them clean toilet bowls with their bare hands", Zimbardo wrote. "Over time, these amusements took a sexual turn, such as having the prisoners simulate sodomy on each other." The prisoners, humiliated and victimised, suffered such emotional distress that Zimbardo, playing the role of all-powerful prison superintendent, terminated the two-week experiment after just six days.

The experience made the key players famous – not least because Zimbardo captured some of the experiment on film and in now-familiar photos. The images showed aggressive-looking guards in tinted aviator shades, clutching police batons, and cowed, shackled prisoners sitting in line with bags over their heads.

The experiment led Zimbardo to conclude that normal people could be transformed into sadistic tyrants or passive slaves, not because of any inherent personality flaws but through finding themselves in a dehumanising environment: context was king. And suddenly, so was Zimbardo. Overnight, he became the go-to expert on prison reform, and over the following decade he appeared at a series of Congressional hearings and advisory panels on the US prison system.

The Stanford prison experiment in 1971 started with lifelike arrests of volunteers

PHILIP ZIMBARDO/STANFORD UNIVERSITY LIBRARIES

The Stanford experiment might have started as a psychological exploration of incarceration, but Zimbardo and countless media commentators since have reached for it to illuminate an ever-widening range of behaviours – police brutality, corporate fraud, domestic abuse, genocide. Every invocation of the experiment has cemented it in the public imagination. The experiment has become enshrined in the psychology curriculum for its simple and compelling conclusion, that corrupt environments can turn good people evil. And of course it has made the leap to popular culture, inspiring documentaries, books and dramatisations. The most recent feature film based on it was 2015's *The Stanford Prison Experiment*, for which Zimbardo was a consultant.

Battered credibility

Zimbardo was elected president of the American Psychological Association in 2002 and in 2012 received the American Psychological Foundation's gold medal for lifetime achievement. Despite Zimbardo's recognition and career honours, and his experiment being in all the textbooks, academic psychology is ambivalent about it. Not surprising, given that the experiment's scientific credibility has taken a battering.

On the one hand, with his high profile and media know-how, Zimbardo has done much to promote social psychology. On the other, the experiment's ethics, methodology and conclusions have long troubled colleagues. The first published criticism, in 1973, attacked the ethics of the study and questioned whether the apparent degradation of the young men was justified, given the experiment's unsurprising result. By 1975, the methodology of the experiment was also under fire. Zimbardo's claims that the results support the view that behaviour is determined by circumstances, not personality have also been robustly challenged by a growing number of researchers since then. After all, critics argued, the guards' behaviour was hardly spontaneous: they knew they were expected to behave like tyrants and were encouraged to do so. And by Zimbardo's own admission, two-thirds of them did not act sadistically, undermining his claim that the situation had an overpowering influence on their actions.

How did a study so flawed become so famous? First, there's the powerful idea that evil lurks inside us all, waiting for the right – or wrong – circumstances to be called forth. The experiment itself may be shocking, but the way it echoes archetypal stories of sinfulness make it hard to shake off.

Then there is Zimbardo himself, a compelling narrator who inserts himself front-and-centre in the drama. In that first published account, Zimbardo admitted to a growing sense of unease over his role as architect of an experiment of such cruelty. His epiphany – helped along by a visit from his then girlfriend, who was appalled at his behaviour – that he too had been corrupted by power was what prompted him to call the experiment off. This acceptance of blame both disarms critics of the ethics of the experiment and suggests that we can trust him to give an unvarnished account of the research. There are echoes of biblical conversion stories; Zimbardo's subsequent involvement in prison reform and more recently in a project to train ordinary people to become "heroes" are a form of atonement. "I want to be remembered not as Dr Evil," Zimbardo tells me, "but as Dr Good."

His public performances, TV appearances and TED talks have an evangelical flavour. Let's face it, "good vs evil" sells, and it circumvents the hassle of trying to understand the subtleties of human psychology.

Zimbardo also has a talent for reframing the "lessons" of the Stanford experiment to capture the prevailing zeitgeist. In 2004, the study made the headlines when it emerged that American military police had abused and tortured prisoners inside Iraq's Abu Ghraib prison. The public debate about how US soldiers could behave so appallingly raised comparisons with the experiment, rekindling

PHILIP ZIMBARDO / STANFORD UNIVERSITY LIBRARIES

Philip Zimbardo captured the degradation of prisoners in his experiment on film

Zimbardo's career as a government-appointed expert. In a *Boston Globe* editorial, he wrote, "The terrible things my guards [at Stanford] did to their prisoners were comparable to the horrors inflicted on the Iraqi detainees." In reality, the terrifying and degrading acts of physical, psychological and sexual abuse meted out at Abu Ghraib were way beyond anything experienced by Zimbardo's prisoners.

But this fresh attention sparked a more critical examination by journalists, who bypassed Zimbardo and sought out the people who took part. Cracks soon appeared in Zimbardo's tightly controlled narrative.

In interviews with researchers and participants, an alternative story emerged. In a 2004 article in the *Los Angeles Times*, journalist Alan Zarembo reported that "prisoner" Douglas Korpi was disgusted with the experiment and Zimbardo's exploitation of it. Both Korpi and Dave Eshelman, who was often depicted as one of the more sadistic guards, spoke of a staged "experiment", and that they had behaved in order to fulfil their role as paid participants. That undermined Zimbardo's insistence that his participants unquestioningly accepted the reality of the dramatic situation.

In 2011, Zimbardo admitted the study's limitations. "It wasn't a formal experiment. My colleagues probably never thought much of it," he told an interviewer. In a high-profile blog post in 2013, textbook author Peter Gray decried the inclusion of the experiment in the teaching of psychology, and later called it "an embarrassment to the field".

In April this year, French author Thibault Le Texier published the book *Histoire d'un Mensonge* ("History of a Lie"). Le Texier compared archival records with Zimbardo's published accounts, listened to audio recordings and video footage of the experiment that had been edited out of public presentations, and interviewed research staff, former "guards" and "prisoners". He concluded that Zimbardo's claims were overblown and his findings hollow.

In a subsequent article on the Medium website, journalist Ben Blum confronted Zimbardo with the contradictions Le Texier had uncovered. Zimbardo pointed to the fame of the experiment as his defence. He later published a rebuttal on his website, infuriating critics of his research by dismissing them as "bloggers" and labelling their findings

"I want to be remembered not as Doctor Evil, but as Doctor Good"

"differences in interpretation". Only time will tell if these recent revelations will diminish the experiment in the public imagination.

If social psychology can be said to have attained the status of religious teachings, then Zimbardo is one of the field's best-known preachers. And like a good preacher, Zimbardo represents the story of the experiment as a timeless parable. "Famous studies like Milgram's obedience to authority, Mischel's marshmallow test, the Stanford prison experiment, they raise moral issues and offer lessons about the psychology of temptation," Zimbardo tells me. "Think about the Lord's prayer. What is the key line? 'Lead us not into temptation, but deliver us from evil.' There are temptations all around us, and who gives in and who resists, this is a fundamental thing about human nature. This is what all these experiments explore and that gives them great public appeal."

In his 2007 bestseller *The Lucifer Effect*, Zimbardo appealed to readers to look inwards. "Could we, like God's favourite angel, Lucifer, ever be led into the temptation to do the unthinkable to others?" He promised readers a journey that will take in "genocide in Rwanda, the mass suicide and murder of People's Temple followers in the jungles of Guyana, the My Lai massacre in Vietnam, the horrors of Nazi concentration camps, the torture by military and civilian police around the world, and the sexual abuse of parishioners by Catholic priests…" Then he adds that the "one… thread tying these atrocities together" comes from "the Stanford Prison Experiment".

Through his story of a descent into the basement hell, the suffering, the epiphany, the ascent, transformation and redemption, Zimbardo offers a powerful message of hope about human nature: we all have the potential to be saints rather than sinners. It's seductive to think that in the fight between good and evil we can all be winners through the redemptive power of psychological knowledge. Shame that, as far the Stanford prison experiment is concerned, it's more showbiz than science. ■

Gina Perry is a psychology writer in Melbourne, Australia


PIZZA
MANUAL

BIG BLACK BOX

We are on the verge of building an exascale computer. But what does that mean – and will we even be able to use it, asks Edd Gent

THERE are few events in the universe more complex than the violent deaths of massive stars. Their explosions are so huge that they can be seen thousands of light years away, and they leave behind mind-bending remnants like black holes and neutron stars.

Making detailed simulations of these colossal supernovae is currently beyond the reach of even the world's most powerful computers, yet Bronson Messer is determined to try. "It's the biggest bucket of physics you can imagine," says Messer, an astrophysicist at Oak Ridge National Laboratory (ORNL) in Tennessee.

Messer is building simulations for Aurora, due to come online in the early 2020s, which could be the first machine capable of one exaflop – a billion billion "floating point operations" per second – making it millions of times faster than your trusty laptop. Exascale computers will provide unprecedented power, perhaps enough to unlock fundamental goals in a broad range of scientific disciplines. Predicting the weather, simulating entire brains, recreating the cosmos and tailoring drugs to individuals could all become possible. That's why the US, China and Japan are racing to build one first.

TOTTO RENNA

This is a multibillion-dollar development effort, fuelled by the need to power such a beast of a machine without bringing the grid to its knees, and to create a communication network that can coordinate all of its many parts. But lurking in the background is a provocative question with no clear answer: once we build such a machine, how useful will it be?

Need for speed

The accepted way of ranking the speed of a computer is by how many calculations it can perform per second. These ordinarily involve representing numbers in a format known as floating-point, which allows you to efficiently encode numbers both large and small. The calculator in your desk drawer probably boasts a handful of floating operations per second (FLOPS), the cutting-edge phone in your pocket several billion and the world's fastest machines – collectively known as supercomputers – millions of times more.

Although the first machine to tick over the exaflop mark should arrive some time in the next three years, it isn't going to solve all the world's problems overnight. "There's nothing magical about certain numbers," says Simon McIntosh-Smith, a high-performance computing researcher at the University of Bristol, UK. Reaching that milestone, however, will push current technology to the limit, and going much beyond may require rethinking the paradigms that got us this far.

For more than half a century, the key to increasing computing power has been to squeeze ever more transistors onto a chip. Since the 1960s the density has doubled roughly every 18 months, producing an exponential increase in performance known as Moore's law after chip company Intel's co-founder Gordon Moore, who was the first person to notice it. In 1974, computer scientist Robert Dennard made another important prediction, noting that as chips shrank, their power consumption stayed in proportion with their area, even as transistor density increased. That meant the power consumed by a set number of transistors halved at every cycle of Moore's law. Engineers used this headroom for decades to make chips run faster without significantly increasing power consumption.

But that trend broke down in the mid-2000s: Dennard's assumptions ignored the baseline power that even the smallest transistor must use. That forced a major rethink. Chip-makers realised they could put multiple processors – the silicon brains that carry out instructions from software – on a single chip. Each of these mini processors is called a core. Splitting programs into chunks and running them in parallel on these cores let computers solve problems faster without boosting the speed of the individual parts, which would also boost power consumption. Even the most basic laptop processor today features two cores, but the world's fastest machine, Summit, which ORNL turned on in June, has more than 2 million.

More recently, the drive for energy efficiency has also fuelled the use of accelerators – ›

"Your laptop probably has two cores – the world's fastest machine has over 2 million"

specialised devices that carry out certain tasks much more efficiently than general-purpose processors. GPUs, originally designed to render graphics but now widely used for artificial intelligence, are one popular variety. They excel at running parallel tasks at low power and are increasingly finding their way into supercomputers – Summit has more than 27,000 of them.

But all this can only take us so far. "If for some magical reason you could actually build an exascale machine from today's technology, nobody could afford to power it," says McIntosh-Smith. Such a behemoth would need hundreds of megawatts, he says. As a rule of thumb, "one megawatt's about a million dollars for a year".

Even if chips are more energy efficient, having more of them means you rack up bills elsewhere: specifically, sending signals from one part of the machine to another. "Moving data within a large-scale computer system consumes over an order of magnitude more energy than is needed to compute the data," says Mike Vildibill, who leads the exascale programme at computer manufacturer Hewlett Packard Enterprise.

Because power consumption rises rapidly with distance when communicating over electrical cables, fibre optics have become the go-to approach for moving large volumes of data between distant clusters of processors within supercomputers. But at the exascale, the cumulative cost of signalling over even millimetre lengths will be a problem.

One potentially revolutionary technology, known as silicon photonics, is allowing us to integrate tiny lasers directly onto chips. That could make communication essentially distance independent, says photonics researcher Keren Bergman at Columbia University in New York. Commercial products of this type have just started appearing, but it is unclear whether they will feature in the first exascale machines. "We can probably just reach over the finish line with the technologies we have on hand," she says. "But to have any legs beyond that, photonics is clearly going to be an integral part."

For all its importance, energy efficiency is only part of the communication problem. Having more processors is of little use if they are starved of data, and increases in flops have been outstripping data movement speeds for some time. Silicon photonics could boost the volume of data that can be shuttled per second by at least a factor of five, says Bergman, but faster conventional optics are needed in the meantime. The memory chips could also be stacked vertically, an arrangement that can boost both speed and power efficiency, but typically costs more and comes in smaller capacities, presenting a tricky balancing act for computer designers.

Parallel universe

Nonetheless, most experts say the roadmap for exascale hardware is fairly well laid out. What may be trickier is building software and algorithms to run across potentially billions of cores. "Every generation of supercomputers leaves some users behind," says William Gropp, director of the US National Center for Supercomputing Applications in Illinois. "That's been a constant problem and I think we're going to see it again."

The trouble is an inherent weakness in parallelism, noted in 1967 by computer scientist Gene Amdahl. His eponymous law says that any program's speed will always be limited by its least parallel part. Gropp compares it to transporting a planeload of passengers from Chicago to New York. Even if you replace the flight with instant teleportation, it will still take each passenger 2 hours to clear security.

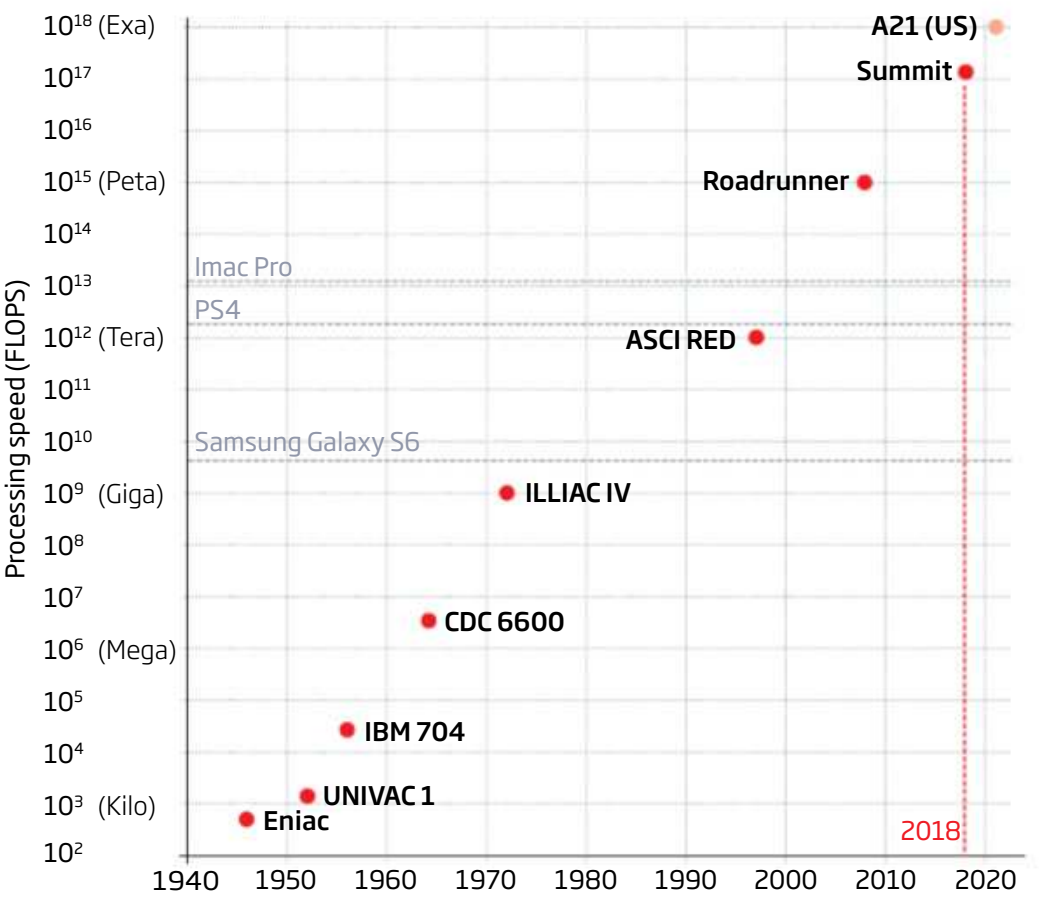
In reality there are workarounds. As you increase the number of parallel tasks on the go, time spent on the slowest part represents ever less of a limitation. But there are hard limits to how many chunks some problems can be split into, says Gropp, and the complexity of massively parallel models can be difficult to understand.

"We are running out of parallelism," says Messer. "Mr Amdahl pokes his head up every once in a while and we try our best to push him back down, but he never goes away." Messer is confident that would-be supernova simulators have enough tricks up their sleeve to get their models working on exascale machines, and he thinks most developers with experience of the world's biggest supercomputers will adapt too. But further progress may require disruptive overhauls of code and programmers' attitudes.

Messer thinks one way forward may be to split problems into the smallest possible sub-tasks and let the machine decide how to divvy them up between processors. But that can make it hard to follow what the program is actually doing, which makes tracking bugs tricky and can present fundamental challenges when running physical simulations. A program that reproduces a specific phenomenon but with underlying steps we struggle to understand is unlikely to provide much insight. "A black box that just gives you an answer is hardly a useful scientific exercise," he says.

Rise of the machines

The number of calculations a computer can perform per second (FLOPS) is set to break the exascale barrier over the next few years



And no matter how perfectly parallel your application is, it still needs to occasionally compare notes between processors, meaning the speed restrictions due to data movement rear up again. One way to tame the problem is to find extra work to do while information is being shuffled around.

Messer's supernova simulations are a case in point. They split the star into chunks that can be simulated separately, but calculating the impact of gravity at each time step requires every processor to broadcast the mass of its chunk to all the rest. While waiting for this to finish, Messer and his group realised that each processor could happily turn to chunk-specific problems that do not depend on gravity, like the rate at which lighter elements are fusing into heavier ones.

Brain simulations pose similar problems because each neuron connects to so many others. At the Jülich Institute of Neuroscience and Medicine (INM) in Germany, researchers have built models that send every simulated neuron's output across the entire network. This approach works fine at the petascale – millions of billions of flops – but would simply devour too much time and memory at the exascale. So the team has developed a way to determine at the outset which neurons need to share activity data, a shortcut which should let them run full-brain simulations on exascale machines. "Then it becomes a really useful research tool for scientists and not only a technology demonstration," says Markus Diesmann, director of INM's computational neuroscience division.

For other simulations, the transition to the exascale could be much more of a struggle. At the European Centre for Medium-Range Weather Forecasts (ECMWF) in Reading, UK, two petascale machines provide 22 countries with 15-day weather forecasts. The software stretches to millions of lines of code built up over decades, and the forecasting models rely on algorithmic building blocks that deal with very different physical processes. Some are inherently hard to parallelise; others are faster than parallel alternatives at petascale, but will start lagging behind once the upgrade to exascale kicks in.

Peter Bauer at the ECMWF thinks flexibility will be key to revamping the code. If, hypothetically, you can get more regional detail at the cost of your model's overall accuracy, that trade-off may be worth making. He says they will also need new software tools that seamlessly adapt models to run on the unprecedented diversity of hardware expected in exascale machines.

The booming field of artificial intelligence is offering further workarounds. Neural network calculations run at half the precision of conventional supercomputer code, but can produce usable approximations faster and more efficiently. Rick Stevens at Argonne National Laboratory in Illinois is developing deep learning models for the Aurora supercomputer to predict how drugs affect different cancers, something that could turbocharge drug development and personalised medicine. Stevens says machine learning is particularly promising in areas with reams of data but little theory to help develop traditional simulations. "I think we are just starting to understand how broadly applicable it is," he says.

But there is a deeper question to confront in the exascale race: whether a focus on flops is always the best way to improve performance. Many simulations use less than a tenth of a supercomputer's peak capacity. Meanwhile the ability to move data is largely ignored in ranking the world's top-performing machines, even though it is often the limiting factor for science applications.

Supercomputing's emergence as the 21st century's equivalent of the space race could be exacerbating the problem. "My concern here is that the preoccupation with the race – the geopolitical posturing here – may ultimately lead to exascale systems that are not the best for what researchers need to do their jobs," says supercomputing consultant Bob Sorenson.

Satoshi Matsuoka, who leads the development of Japan's "exascale" machine, says the country has deliberately set different goals. The objective is to run applications up to 100 times faster than on their existing K supercomputer – a 10-petaflop machine – by focusing development on data movement rather than raw flops. He says candidly that the post-K computer will not hit 1 exaflop, but he is also confident it will run science applications faster than competing first-generation exascale machines.

Doug Kothe at ORNL, who leads the US Exascale Computing Project, doesn't think the exascale race will compromise the real-world performance of the machines that emerge. Although the US is chasing 1 exaflop, it is also targeting a 50 times speed-up in applications over its 17.6-petaflop Titan supercomputer. With the right priorities, says Kothe, "the first wave of exascale platforms will not be 'stunt systems'" that can only run a limited number of niche applications.

As for what might come after exascale, things look wide open. In an era where Moore's law is starting to falter, many predict ever more specialised hardware. Future supercomputers could contain a broader variety of processors and architectures than ever before, or even look entirely different (see "What about quantum?", above left). If Messer wants to keep watching stars explode, his job is going to get a whole lot more complicated. ■

WHAT ABOUT QUANTUM?

Even the world's fastest computers (see main story) might one day be obsolete. Enter quantum computers. Instead of encoding information in the same way ordinary computers do, these machines could harness weird quantum effects to let them quickly solve problems that would take millions of years for even the fastest classical computers.

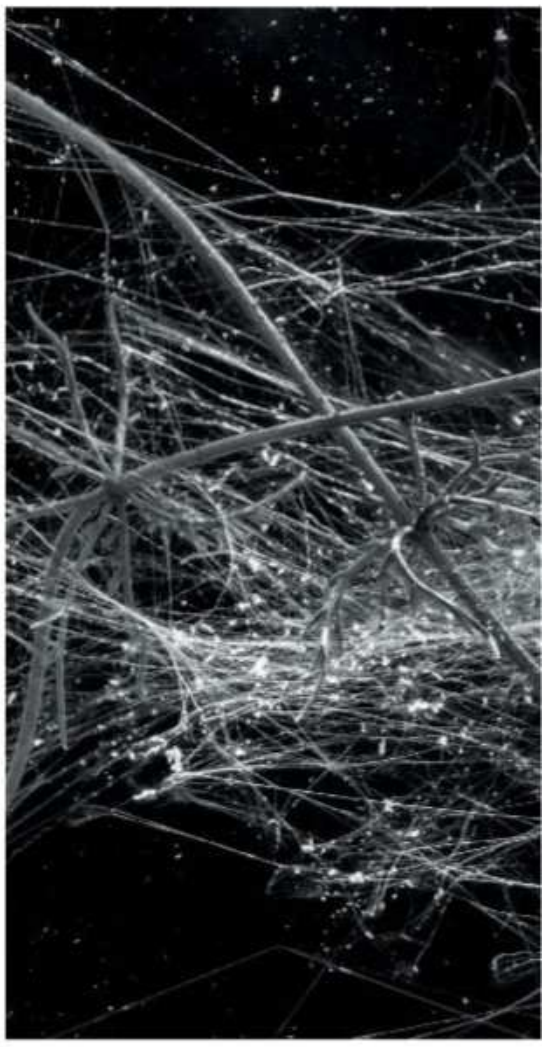
The same quantum quirks may limit the tasks they can perform, but within five years they could compete with their classical counterparts on problems like molecular simulation, materials modelling and optimisation, says John Morton, a quantum computing researcher at University College London. Morton thinks they will probably solve their first problem beyond the reach of conventional computers within 12 months.

While this first test is likely to be designed to favour the quantum computer, he says, "this milestone will mark the start of a new era where quantum software, tailored to the capabilities of early stage quantum hardware, can begin to tackle useful problems."

Edd Gent is a writer based in Bangalore, India

Why Saraceno's balloon art is more than hot air

Forget doomy "Anthropocene" ideas, says artist Tomás Saraceno. If we're serious about saving the planet we need hope, he tells **Simon Ings**



Above, spider-inspired art; below are Saraceno's signature balloons

On Air by Tomás Saraceno, Palais de Tokyo, Paris, 17 October to 6 January

THE Argentine-born artist Tomás Saraceno maintains a studio in Berlin – if you can call a disused chemicals factory a studio. There is nothing small about this operation. Saraceno, who trained as an architect in Buenos Aires, now employs hundreds of people, with specialisms ranging from art history and architecture to biology and anthropology. If you're serious about saving the world, you need this kind of cross-disciplinary team, I suppose.

Though Saraceno hasn't exactly promised to save the world, he has been dropping some big hints. His utopian installations include Cloud Cities at Hamburger Bahnhof, Berlin, in 2011 – a collection of geometric, inflated shapes. Even by the time of his Observatory/Air-Port-City show at London's Hayward Gallery in 2008, these shapes contained autonomous residential units. A network of habitable cells floated in the air, combining and recombining like clouds.

A year later at the Metropolitan Museum in New York, gallery-goers got to explore these spaces via 16 interconnected modules made up of glass segments held in place by steel cables. And in June 2013, the K21 gallery in Düsseldorf invited visitors to wander more than 25 metres above the gallery's piazza across a web dotted with inflated PVC spheres.

This is Saraceno's answer to our global problems: he wants us to take to the air. That's why he coined the term "Aerocene" for one of his projects. He wants people to think of climate change in terms of possibility, playfulness and, yes, escape. "We live beneath an ocean of air," he once wrote, as he sketched his utopian vision of a city in the clouds. "But we've yet to find a way to inhabit it."

Near his Berlin studio is a scruffy public park. Part of it is marked out for football. Behind one goal stands a graffitied stretch of the Berlin Wall. Today there's another attraction: two men are running back and forth, trying to fill a black bag as big as a minivan with air. It is a fine, windless day; the air in the bag heats up quickly, and once it is sealed, the container rises into the sky. A bag no longer, it is clearly recognisable as one of Saraceno's signature tetrahedral solar balloons.

These black balloons have been plying the skies since 2007. They are mascots of the artist's multi-stranded effort to combine engineering, architecture and the natural sciences to create a new, democratic kind of environmental art, made of bubbles and aerial platforms and webs. An art that mitigates climate change, he says, and makes the sky habitable, by establishing a modular, transnational settlement in the skies through solar balloons that require no fuel at all. An art that ushers in utopia.

Could it be that this chap is just playing about with balloons? Trying to calculate Saraceno's level of seriousness is half the fun. Over lunch, for instance, he tells me that he wants to return us "to a sort of Mayan sensitivity towards celestial mechanics".

AEROCENE EXPLORER PERFORMANCE. AUGUST 7, 2017. SALINAS GRANDES, JUJUY, ARGENTINA. WITH THE SUPPORT OF CCK BUENOS AIRES.COURTESY THE AEROCENE FOUNDATION AND CCK AGENCY. PHOTOGRAPHY BY JOAQUIN EZCURRA, 2017, LICENSED UNDER CC BY AEROCENE FOUNDATION 4.0

But some of his efforts are admirably practical. The balloon I'd just seen being demonstrated was an Aerocene Explorer: it comes in a backpack complete with instructions on how to create and fly lightweight sensors. Any data collected can be uploaded and shared with Aerocene's online community, via a website where participants from all over the world are sharing their experiments and innovations.

Practicalities aside, much of Saraceno's work is simply beautiful. For a show opening at the Palais de Tokyo in Paris on 17 October, the team is busy building playful orreries, mechanical models of the solar system that combine planetary orbits with the physics of soap bubbles and webs spun by his pet *Cyrtophora citricola* spiders.

These unbelievably delicate

confections will be on show with some mirrored umbrellas that also double as solar cookers. When arranged in concentric circles, Saraceno imagines that in the manner of a solar thermal power plant, the umbrellas might even concentrate enough heat to inflate a large balloon. He hopes to try out the idea when he takes parts of his sprawling Aerocene endeavour to Miami this December for the Art Basel fair.

Meanwhile, there are myriad things to organise for Paris: workshops, concerts, public symposiums uniting scientific institutions, researchers, activists, local communities, musicians and philosophers. As he says: "People aren't very interested in simple ideas. You have to give things a little bit of complication to get the audience to engage."

He found this out the moment he started using solar balloons. The balloons, which work by simply zipping up some air in a heat-absorbing bag, have been around since the 1970s. His own projects have demonstrated their usefulness in meteorology, pollution monitoring, even passenger transport. In 2015, he flew in a tethered solar balloon over the dunes of White Sands in New Mexico, where the US launched its first rockets and where the world's first tourist spaceport is located. The Massachusetts Institute of Technology got in on the act, and created technology so that you can use the Aerocene.org website to plan a meteorologically feasible journey, by balloon, from Point A to Point B, anywhere on Earth.

"Rats saved at the point of giving up fought for life 240 times longer when returned to danger"

Here's the paradox. Saraceno's work has always been playful, and part of the game, he explains, has been "trying to sell this work as some sort of global solution to something". But while his visions of an airborne utopia remain as remote as ever, his Aerocene project has spawned a foundation that uses lightweight balloons for climate activism and pollution monitoring. And even the absurd spectacle of someone jetting from country to country to fly fuel-less balloons has become part of the art, as Saraceno's studio begins to record his own carbon footprint.

Saraceno makes an important point about how we address climate change in our lives. The trick, he says, is not to let the perfect get in the way of the good. Escapism is fine. He has no time for the way so many artists and pundits are ringing humanity's death knell. He has a special contempt for the lazy way the word Anthropocene crops up now in every climate conversation, as if, with the advent of this putative new era, our doom was sealed. "What a great way for a small number of people to disempower and demotivate us," he says.

Given the seriousness of our environmental bind, isn't escapism a bit irresponsible? Saraceno points me to a 1957 paper by psychobiologist Curt Richter. His gruesome experiments left rats to drown in water-filled containers from which they could not escape. But if he briefly rescued rats at the point they gave up swimming, and then returned them to the water, those rats continued to fight for life 240 times longer. Richter concluded that they had learned that there was hope. Faced with challenges on a planetary scale, we are scrambling for our lives, and can see no way out. "We need the energy those rats got when they saw some small hope," says Saraceno.

I hadn't expected our conversation to take this dark turn, but creating such small glimmers of hope is his business. If he is a joker, then he is one in the best sense of the word.

Should we take Saraceno's work seriously? I was doubtful, but now I think, why look a gift horse in the mouth? He enthuses people. He gets us thinking. And he is right: a little hope goes a long way. ■

DON'T MISS

Play

Resynth, an award-winning musical game from Polyphonic LP, arrives on Steam for PCs and Macs this week. It is part puzzle, part musical instrument, part mixing desk. There are some sweet loops waiting to be unpacked here – one of the developers is a jazz pianist.

Visit

The Manchester Science Festival (pictured) runs from 18 October. Shobana Jeyasingh's flu pandemic-inspired dance piece *Contagion*, a "black hole experience", and an art exhibition, Electricity: The spark of life, are among the attractions .

Read

Todd Neff's book *The Laser That's Changing the World* (Prometheus) features how we are using lidar to map other planets.

Listen

The Orchestra of the Age of Enlightenment returns to King's Place in London to explore *Bach, the Universe and Everything* on 21 October. Non-musical guest Dallas Campbell will give a talk on the past and future of space travel.

Watch

Documentary *Science Fair* reveals a subculture as wonderful as it is weird. Its focus is the 1700 school students from around the world who attend the Intel International Science and Engineering Fair in Los Angeles to battle for prizes.

TOP: ARGYRONETA AQUATICA IN THE AIR BUBBLE OF THE UNDERWATER WEB SHE BUILT AT STUDIO TOMÁS SARACENO, 2017. COURTESY THE ARTIST; TANYA BONAKDAR GALLERY, NEW YORK; ANDERSEN'S CONTEMPORARY, COPENHAGEN; PINKSUMMER CONTEMPORARY ART, GENOA; ESTHER SCHIPPER, BERLIN; RUTH BENZACAR, BUENOS AIRES, ARGENTINA. PHOTOGRAPHY BY STUDIO TOMÁS SARACENO, 2017

Newtworld is our world

Immersing us in a terrifying future, this is smart, sci-fi theatre at its best, finds **Lydia Nicholas**

War with the Newts, written and directed by Knaive Theatre's Tyrrell Jones, staged at the Bunker Theatre, London, to 27 October

RICHARD DAVENPORT / THE OTHER RICHARD

CZECH author Karel Capek wrote *War with the Newts* in 1936 under the shadow of rising fascism. To him "the world was looking unbelievably bad economically, and politically still worse". Bold, brutal, bitingly funny, his satirical sci-fi novel was a complex portrait of consumerism, nationalism, racism and techno-utopian hopes of a better world, all used to mask or excuse exploitation.

Tyrrell Jones's reimagining is a technically accomplished, immersive show, as urgent and terrifying as it is entertaining. Jones projects Capek's original themes onto a post-Brexit UK. Its focus is the crew of an oyster trawler off the coast of Scotland.

When the crew encounters an underwater species of intelligent newts capable of performing simple jobs in return for trinkets, they see opportunity. What begins as a chance to save their livelihoods soon grows into an enormously profitable and powerful global corporation breeding, selling and exploiting millions of "helpful little creatures". But the corporate promise of progress towards a post-work paradise collapses and, amid unrest from displaced human workers, the newts rise up.

The show plays on our globalised, hyperconnected world, which displaces the consequences of our actions to other parts of the planet. Our plastic washes up on other beaches, our cheap consumer goods are built far away in unsafe factories, using minerals mined in conflict zones we will never see. As Capek's original suggested, this is no oversight, but a key feature of consumerism. Any consumer utopia must shift the graft, suffering and pollution onto others that we enslave, dehumanise or exploit in the name of trade and development. It is a system designed to make the suffering invisible to us, or the sufferer inconsequential.

Because of its physicality, live performance can create an encounter that, even when it becomes uncomfortable, grabs and holds our attention. *War with the Newts* never lets its audience melt into the dark; we are here, in danger, and perhaps to blame.

The discomfort starts early. Entering through a smoky tunnel, audience members are assessed and their hands stamped. We become the pitiful survivors of an atrocity, travelling through a war zone in an oyster trawler to the last human outpost.

Capek's novel mixed prose with other formats, such as newspaper clippings and faux-academic reports. Knaive Theatre also draws on a varied toolkit to build its future world, and illustrate the moral failure that capsized it.

Three shipboard AIs introduce us to cheery scenes of edited history. But as tech and story break down, other scenes slip through: a newt dissection, a call-in show in which presenters make convoluted logical leaps to deny newt intelligence and their capacity to suffer and love.

"Any consumer utopia must shift the graft, suffering and pollution onto others we enslave or dehumanise"

A roster of virtual and physical characters, all performed with great skill by Nadi Kemp-Sayfi, Everal Walsh and Sam Redway, sketch a detailed world, both funny and threatening. The immersion and jarring changes in tone are supported by excellent lighting and Robert Bentall's live sound mix, which evoke both the open spaces, and hard work of a crew on stormy seas and a claustrophobic siege as monsters tear through the trawler's walls.

Actors Nadi Kemp-Sayfi and Sam Redway create a threatening world

The swings between horror and humour can be dizzying. Redway's Hugh Grant-like ambassador to the newts has the audience in hysterics with an etiquette error; minutes later, cruelties against the newts are listed calmly by Kemp-Sayfi's impassive lawyer.

Though its metaphors range from sharp to obvious, as a whole, the play is faithful to the complexities of Capek's novel, and its intricate links between racism, consumerism and techno-utopianism. Whatever strange reflection of our world the play shows us, we cannot turn away. ■

Lydia Nicholas is a researcher in data and culture

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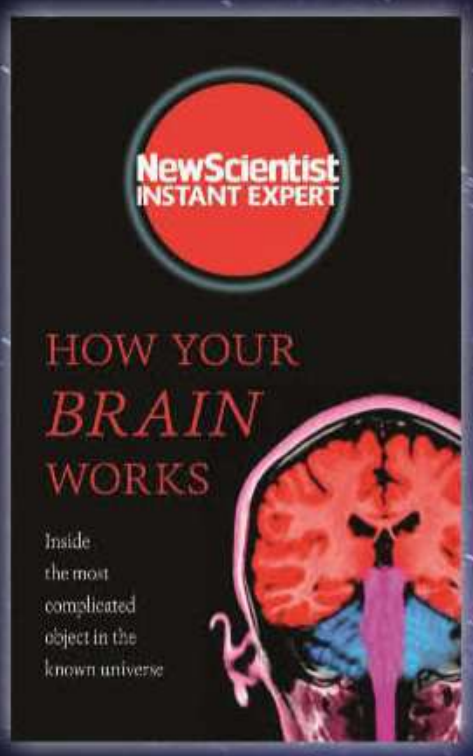

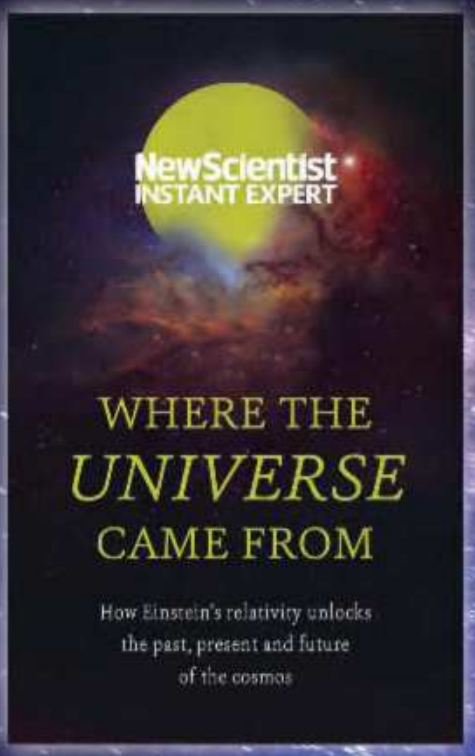

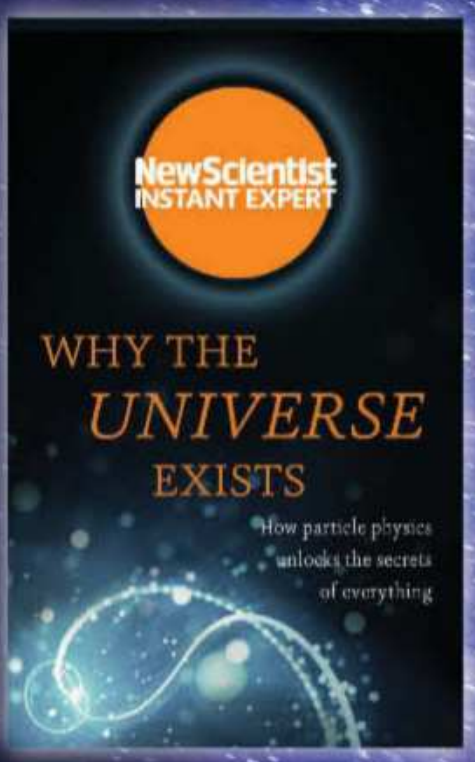

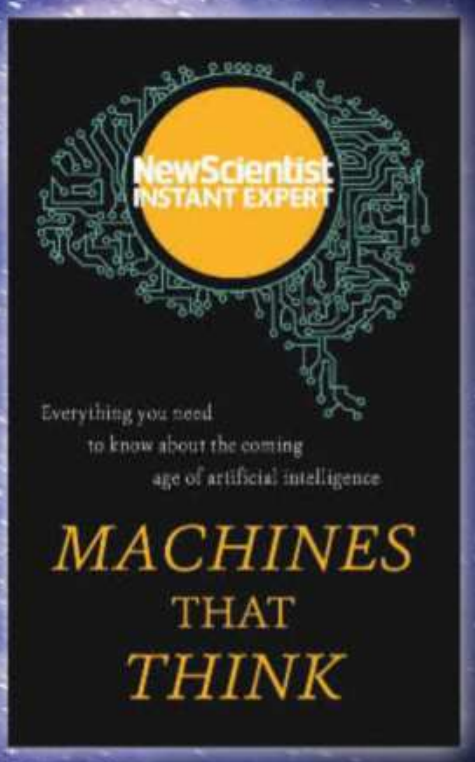

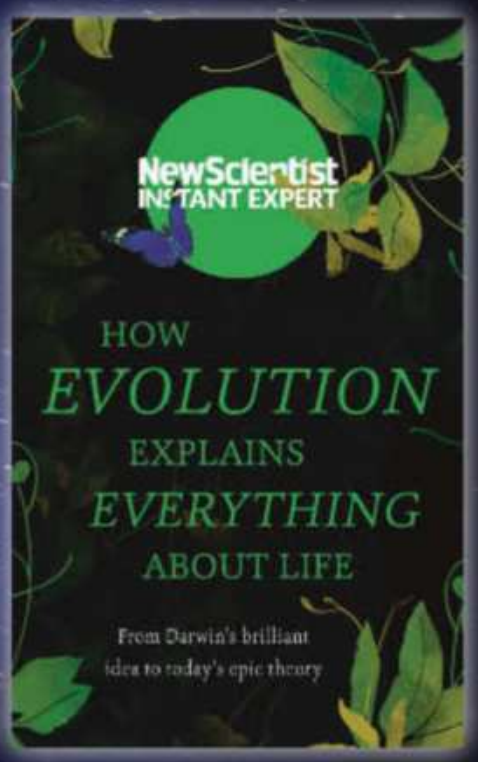

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THE UNIVERSITY OF CHICAGO

Position Title: **Research Associate Professor**

Req **# 03919**

Department of Chemistry at The University of Chicago invites applications for the position of Research Associate Professor. The successful candidate will be responsible for maintaining a research program and advise graduate students in Theoretical or Computational Chemistry. The candidate is expected to collaborate with experimental and/or theoretical faculty within the department. Ideally, candidates should have demonstrated ability to raise support for their research and lead collaborative projects.

Candidates must have a doctorate in Chemistry or related field, along with at least five years of postgraduate research and teaching experience in Chemistry. The successful candidate will have demonstrated competence in teaching, and have experience mentoring graduate students in Chemistry. Candidates must have evidence of publication and research dissemination.

Applicants must apply online at the University of Chicago's Academic Jobs website **https://tinyurl.com/yd8tkptv**, and must upload a curriculum vitae and cover letter.

Review of applications will begin **November 15, 2018** and will continue until the position is filled.

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Department of Neuroscience

New Haven, CT 06520-8001
http://medicine.yale.edu/neuroscience/index.aspx

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The Department of Neuroscience at Yale University seeks to hire faculty in any area of neuroscience, with a preference for candidates who use neuronal or systems level analysis to investigate circuits, behavior or cognition in health and disease.

Emphasis will be placed on recruiting at the level of Assistant Professor, but excellent applicants at Associate Professor level will also be considered. We seek candidates with an exceptional track record, potential for outstanding future achievements, and a wish to participate in a dynamic and recently expanded neuroscience community at Yale that includes the Kavli Institute for Neuroscience, the Program in Cellular Neuroscience, Neurodegeneration and Repair (CNNR) and the Swartz Program in Theoretical Neuroscience. We are especially interested in candidates who will contribute to the diversity of our academic community. Candidates will be supported by a generous start-up and ongoing salary support, and are expected to develop a productive and innovative research program that will include the opportunity to participate in graduate and medical education.

Candidates must hold a Ph.D., M.D., or equivalent degree. Please send a cover letter, curriculum vitae, up to 3 representative publications, a research plan (strictly limited to 2 pages), and arrange for submission of 3 letters of recommendation. All application materials should be submitted electronically through apply.interfolio.com/54771. Applications will be reviewed as they are received and until the positions are filled with priority given to those applications received by **November 17, 2018**.

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WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

Professor of Chemistry

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Ph.D. in Chemistry or related field is required prior to the start of the appointment. Area of specialization within chemistry is open. Candidates for the Assistant Professor title must have demonstrated potential for internationally recognized research in his/her field of specialization. Tenured candidates must have demonstrated excellence in scholarly research, teaching, and service. The successful candidates will be expected to teach chemistry courses at the undergraduate and graduate level. Mentoring of graduate and undergraduate students is required, as is the development of an internationally recognized scholarly research program. Professional and university service are also required.

Please go to **https://academicjobsonline.org/ajo/jobs/11873** to view the posting and begin the application process. Application materials including cover letter, current CV, teaching statement, research experience summary, and a concise description of research plans will be required for all applicants. Applicants will also be asked to provide the names and contact information for three professional references. To guarantee full consideration, applications must be received by October 18, 2018. However, applications will be accepted until all positions are filled.

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HARVARD UNIVERSITY

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Faculty of Arts and Sciences Department of Chemistry and Chemical Biology

Position Description: Candidates are invited to apply for a tenure-track assistant professorship in physical chemistry, broadly defined, including experimental and theoretical research in areas such as but not limited to atomic and molecular physics, biophysical chemistry, condensed matter, quantum science and ultrafast spectroscopy. The appointment is expected to begin on July 1, 2019. The tenure-track professor will be responsible for teaching at the undergraduate and graduate levels. We are seeking candidates who have an outstanding research record and a strong commitment to undergraduate and graduate teaching.

Basic Qualifications: Doctorate or terminal degree in chemistry or related discipline required by the time the appointment begins.

Additional Qualifications: Demonstrated experience in teaching is desired.

Special Instructions: Please submit the following materials through the ARIeS portal (https://academicpositions.harvard.edu/8371). Applications must be submitted no later than October 15, 2018.

1. Cover letter
2. Curriculum Vitae with publications list
3. Teaching statement (describing teaching approach and philosophy)
4. Outline of future research plans
5. Names and contact information of 3-5 references. Three letters of recommendation are required, and the application is complete only when all three letters have been received.
6. Selected publications

Contact Information:
Susan M. Kinsella, Search Administrator, Department of Chemistry and Chemical Biology, Faculty of Arts and Sciences, Harvard University, 12 Oxford St., Cambridge, MA 02138.
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EDITOR'S PICK

There are more reasons to lose weight

From Christine Rogers, London, UK
I was interested in your article on fat acceptance and the argument over the effects of being overweight (29 September, p 20). I am 79, female and overweight, and my weight rose from 7.5 stone (48 kilograms) in my 20s to 76 kg today. I have weighed as much as 90 kg but have lost weight gradually and without stress over the past two years.

You mention model Tess Holliday. She is 33 and can cope with problems now that she will find distressing and debilitating in later years as she loses suppleness. These problems include the inability to cut or paint one's own toenails; difficulty in fitting into and getting out of a bath, toilet cubicles, public transport seats, theatre and restaurant seats; lack of choice in clothes and difficulty with housework, gardening and lifting or playing with children or grandchildren.

It is worth the effort to lose weight for many such small, practical reasons, in addition to the health issues you mention. My advice is to take it slowly, weigh in every morning to get a good idea of your progress and never shop for food when you are feeling hungry.

In praise of fibre as a way to help bowel health

From Alan Desmond, Shaldon, Devon, UK
You provide an excellent overview of the current scientific evidence on gluten and the complex world of the gut microbiome (15 September, p 32). I was, however, puzzled by Peter Whorwell's amazement at "how many vegetables people are eating these days".

Dietary guidelines in the UK recommend a daily intake of at least 30 grams of fibre. According to the UK Scientific Advisory Committee on Nutrition, the majority of UK adults fall far short of this target: average daily intake is just 18 grams.

This is a real public health concern. Fibre-rich diets afford significant protection from cardiovascular diseases, coronary events, stroke and type 2 diabetes. Cancer Research UK recently estimated that 28 per cent of bowel cancers in the UK are caused by eating too little fibre.

In my experience as a family doctor, the average patient with symptoms resembling irritable bowel syndrome has dietary intakes in keeping with the low-fibre habits of the nation. Most benefit from advice to gradually increase their intake of fibre while focusing on healthy whole foods, including fruits and vegetables.

Things we believe about economics and the world

From Tom Smith, Saint Louis, France
Pascal Boyer assembles a convincing array of observations on how the general population doesn't understand the economy – or, at least, on how

"I'd like to have my mind read; maybe they can make sense of the jumbled mess in there"

Constance M is less alarmed than many about the prospect of technology that could read minds (29 September, p 28)

it doesn't share the same understanding as the economists he is familiar with (22 September, p 40). But behavioural economics has fairly comprehensively killed the idea that we behave anything like the "rational economic man" who is at the root of the classical theory he draws on.

This hasn't fazed the free-market enthusiasts, whose models depend on classical assumptions. A common form of argument in econometrics is to build a complex model, observe that its predictions don't fit the data, and then suggest that it is the world that needs to change to fit the model.

From Peter Basford, London, UK
Your article on folk economics states that the "wealth pie" being finite is a flawed idea. This is far from self-evident. We have one planet, and we don't account for negative wealth such as forest loss or damage from climate change.

Another of the "flawed ideas" discussed is that sellers can fix prices. But corporations do often impose prices by forming cartels. And government intervention in markets can work. Governments can lower prices, for example by providing council houses if rents are unaffordable. Each of the "flawed ideas" surely deserves its own article.

From Roger Fletcher, Hyde, Greater Manchester, UK
Boyer allows no room for the sort of redistributive taxation policies that from 1945 to the early 1980s helped to narrow the gap between rich and poor in the UK. Since then, right-wing taxation policies have been reopening the gap, to the detriment of the country as a whole. Yes, that's a left-wing view, but it is also worthy of discussion.

From Merlin Reader, London, UK
Adam Smith argued in his *Wealth of Nations* that for free markets to work, employers must not be allowed to confer. And "free" markets are in fact highly regulated, to prevent adulteration of food, for example. That does happen without regulation. And consumers cannot choose lower prices if no companies offer them.

From Nathaniel Hellerstein San Francisco, California, US
Boyer says that it is as if the human mind is designed to misunderstand mass-market economics. But retroactive maladaptation would be hard to explain.

I offer a counter-proposal: it is as if mass-market economics is designed to be misunderstood by human minds. This is easy to explain. Those in charge of such economies have a vested interest in being misunderstood. For instance, Boyer declares it a flawed idea, that "wealth is a fixed-size pie – the poor get poorer when the rich get richer".

Yes, over the past 40 years US gross domestic product has quadrupled; but wages for the vast majority have barely budged. So for them the "flawed idea" is a statement of plain fact.

How to pin down an antimatter particle

From Mark Barrett, Colchester, Essex, UK
You say again that a particle can be "in two places at once" (15 September, p 8).

This is a statement made by an organism that has a theory of the microscopic, which it tries to interpret with the cognitive systems that it has ›

evolved to allow it to survive at a macroscopic level.

In Richard Feynman's path integral formulation of quantum mechanics, a particle can take any path between measurements – but this is not to say it is actually everywhere at once.

We might cling to our common sense by saying it is as if the particle has been in two places at once – or indeed an infinite number of places. But this does not help with the conceptual chasm. The fact that quantum mechanics is entirely outside our mental apparatus, which is tuned to the macroscopic world, makes its invention perhaps the most remarkable feat of all science.

From Koos Dering, Amsterdam, Netherlands.
You say the interference pattern may be interpreted as evidence that particles have been in two places at once. But the pattern is also evidence that they have not been "seen" – in quantum jargon, observed – in either place. That would certainly have extinguished the pattern.

Some ways to green your laundry day

From Guy Cox, St Albans, New South Wales, Australia
Congratulations to Enid Smith for blowing the whistle on washing machines that accept only cold water (Letters, 8 September). We live off-grid, running on solar power, and our only water supply is what falls on our roof.

When we went to buy a washing machine, the only one with a sufficiently low power consumption had a one-star rating out of six for energy efficiency – because the calculations are based on heating the wash water with electricity.

We found a top-loading machine that has hot and cold water inlets. I gather these are hard to find in the UK.

From Stuart Hubbard, Quarff, Shetland, UK
Smith writes that she was unable to find a washing machine that took warm water from the domestic system. The fact that washing machines need high-pressure water used to mean there was no option but to connect them to the cold water supply. Many houses now have high-pressure hot water systems. If her solar panels deliver high-pressure water, she could supply the washing machine through a thermostatic mixing valve – although these are not cheap.

We need some precision about etching

From Rosalinda Hardiman, Portsmouth, Hampshire, UK
Clare Wilson reveals some of the earliest known human mark-making, possibly pushing back the beginning of the history of art (15 September, p 7). I am irritated, though, by the use of "etching" instead of "engraving" or "incising" to describe how the marks were made.

The distinction is important to me as an art historian: to etch is to engrave with acids or corrosives. To state that "etching is a simpler technique than drawing with a crayon" reverses the actuality.

Etching was developed in the Middle Ages and it may have been used by the Romans for metal decoration – but not earlier. Art terms deserve the same stringent accuracy as scientific ones.

People are infinitely inventive so I have hope

From Chris Daniel, Colwyn Bay, UK
Alastair Brotchie laments the loss of his theatrical job to digital technology (Letters, 8 September). I sympathise with him and others whose livelihoods are replaced by automation and who are excluded from the benefits it brings; but I am optimistic for the future.

Humankind has continually found ways of making tasks easier to save time and effort and this has invariably displaced human labour. The "leisure" or "post-industrial" society that was supposed to arise has never materialised: by all accounts we are busier than ever.

People are infinitely inventive and resourceful, and if one type of job becomes unnecessary we turn our attention to other things.

TOM GAULD

For the record

- **Thirsty work: the power consumption of Neal Tai-Shung Chung's desalination plant is 1 kilowatt-hour per cubic metre of water (8 September, p 32).**
- **Heavy. The quasar called OJ 287 has the mass of 18 billion suns (22 September, p 35).**
- **The female physicist we pictured at New Scientist Live is Melanie Windridge (29 September, p 24).**
- **The muscles that control Ian Burkhart's hand and fingers are stimulated through a sleeve on his forearm (29 September, p 7).**

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RUSSELL COBB

Bat slippers

To navigate your way around the house in the dark, try this ingenious footwear

"I try to tidy before bed, but the kids' Lego often litters the landing, making it hard to creep to the toilet at night," says Lou Tripp. "Turning on the light wakes everyone, but so do my howls of pain when I step on a stray piece. How can I keep the family sleeping soundly and avoid injury?"

A nocturnal navigation aid could stop you from being the thing that goes bump in the night. But form is important in this instance: a clever device is no use if you leave it by your bedside in somnambulant stupidity. My solution had to involve something I would take to the toilet anyway. A very short process of elimination pointed to slippers.

For the function, I took inspiration from evolution, looking to animals that have solved a similar problem: bats. I figured that by combining sonar sensors and a lightweight, programmable Arduino board, I could echolocate obstacles with my feet. One sensor on the front and outer side of each slipper should be sufficient, even if I accidentally crab-walk my way towards danger.

How should the slippers warn me? Audio would force me to fit the rest of the household with ear plugs at night. Instead, I added small vibration motors beside each sensor and programmed them to up their output as they got nearer to objects – like wearable rumble strips.

The next hurdle was power. Small batteries don't add too much weight, but if I'm half asleep, I am unlikely to remember to switch on my slippers before I set off. A pressure switch is no good as it would turn off with each step. Conductive Velcro is fiddly and most latching buttons would be uncomfortable underfoot.

The alternative I devised was a docking station by the bed. Magnetic switches in the heels of the slippers are held open by a magnet in the bed frame. Walk away from where your bat slippers have been roosting and the switch springs shut, closing the circuit and activating the footwear.

The bat slippers have given me confidence in my midnight manoeuvres. One downside is that they might be popular with the kids. And that means they will probably get left on the landing. **Hannah Joshua** ■

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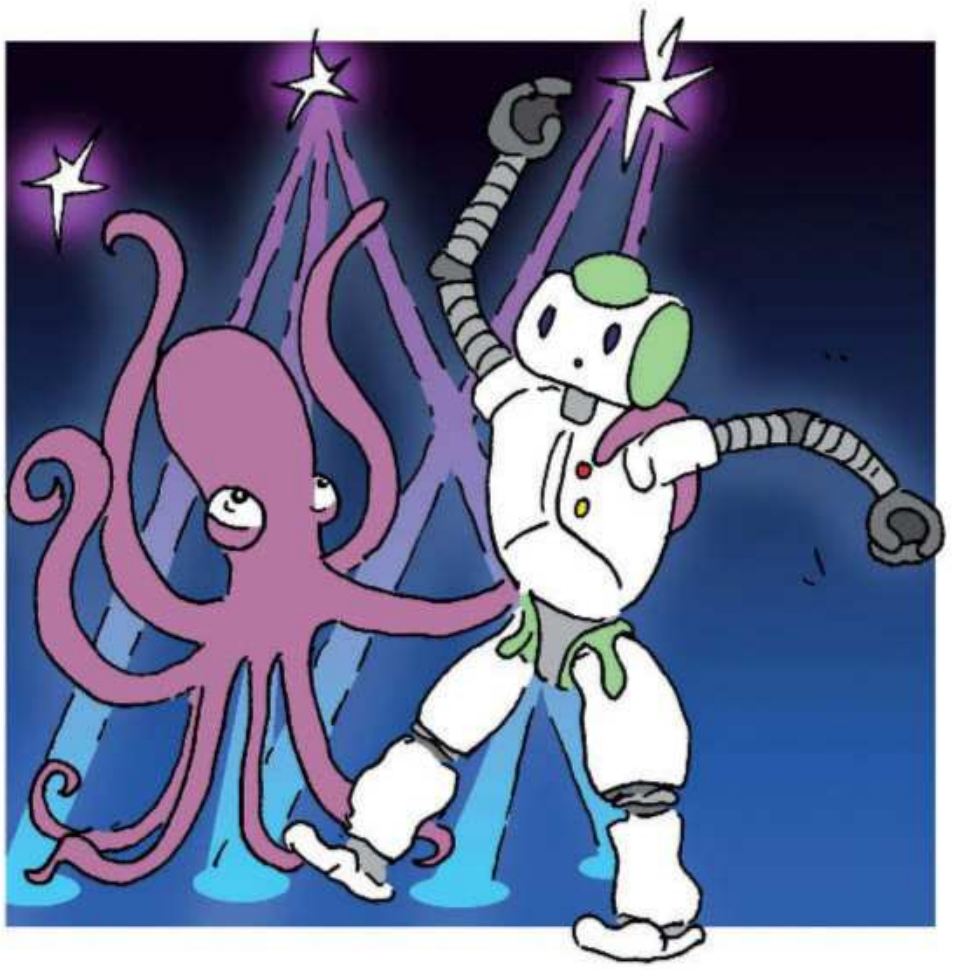

PAUL MCDEVITT

FEEDBACK is buzzing at the startling news that octopuses fed MDMA go all huggy (29 September, p 18). Cephalopods can change skin patterns, maybe to communicate (6 October, p 39). We wondered what might signal "it's not that stuff they put in the water, I really, really love you", but then realised that it may be impossible to differentiate that message from "let's dance to dawn".

It inspired us, though, to begin a search for hug-related research. We immediately found "The importance of teaching robots to hug", in the August edition of *IEEE Spectrum* and about a talk by Alexis Block and Katherine Kuchenbecker of the haptic intelligence department at the Max Planck Institute for Intelligent Systems in Stuttgart, Germany, on "Emotionally supporting humans through robot hugs".

They found that people generally welcomed the soft and warm hugs from their HuggyBot. But when it persisted for 5 seconds after they attempted to disengage, this caused "low-key panic". Not dissimilar to some dance-floor experiences, then. We'd welcome more examples of scientists embracing the study of embracing.

THE press releases our colleagues receive are sometimes weird and wonderful. Presently prominent are those promising exciting applications of blockchain technology, best known for enabling bitcoin – despite its soaring energy consumption (4 November 2017, p 8). A recent example promises the "inspiring story of two entrepreneurs who teamed up on the soccerfield back in 1990".

So far, so heart-warming. This one gets better. They promise "to leverage blockchain technology to drive real business decisions". How? With a "ground-breaking Visual Workflow Designer that gives anyone the ability to craft powerful Blockchain-based solutions with no coding skills". The website goes on: "generated code is deployed, maintained and updated as blockchain specific smart contracts".

So they have a blockchain-based solution to the problem of developing blockchain-based solutions. Suggestions for third-order solution solutions will be routed by our resident neural-network wetware filter to the cylindrical file under the desk.

MORE old-fashioned pseudoscience continues, meanwhile, unabated. Galen Ives recently came across a full-page advert on the back of a magazine for "Quantogram phone and wifi harmonisers". These are, apparently, designed to protect us from the horrors of "electronic smogs and EMFs".

As a Feedback reader, Galen is duty-bound to research his initial scepticism. A quick look at quantogram.com revealed a good deal of waffle about quantum mechanics, with the priceless observation that "some Quantum Physicists are having great difficulty explaining Quantum Mechanics as the research is now going into parallel dimensions, multiple states, and other findings with which most people struggle to comprehend".

Taking his responsibilities seriously, Galen emailed the purveyors of this waffle to ask how their Quantogram harmoniser actually works. They replied quickly, telling him: "Inside the self-adhesive Quantogram Phone Harmoniser is specific calculated mathematical equations that are embedded to effect change and provide strength and protection for the user." Are the equations then written on parchment as a kind of talisman?

ANOTHER duty of Feedback readers is to spot non-obvious and possibly genuinely important connections. We reported on one of science's unsung heroes, James Croll, the janitor who first linked ice ages to variations in Earth's orbit (25 August, p 34). John Reid recalled that Croll did in fact get some credit, notably in Robert Ball's 1890 book *The Cause of an Ice Age* (Letters, 29 September).

Penelope Stanford zoomed in on Reid's observation that his copy of the book was presented as an English prize in a girls' school. "Somewhere," she writes, "probably at the end of the 19th century, a scientific work was presented as the prize… to a girl. I wonder about the teacher, presumably a woman, and the girl: which one made the choice, and what happened to the prizewinner afterwards?" We eagerly await the next instalment.

WE REPORTED the theft of creepy-crawlies valued at $40,000, including scorpions, millipedes and a six-eyed sand spider, from the Philadelphia Insectarium (15 September). Alan Wills writes to observe that none of these arthropods that we cited as examples is actually an insect. "No wonder the ex-employees

who supposedly perpetrated the theft were disgruntled ," he posits. "Doubtless they know their taxonomy better than the marketing people who dreamed up the name of the place, and simply sought to adjust the exhibition so that it actually contains what it says on the label."

The movement for taxonomic exactitude has until now expressed its correct fury in letters to our editor. The suggestion that it has acquired a direct-action wing is disturbing.

Andrew Shearman saw the rolling banner on Sky News say Donna Strickland is the first woman for 55 years to win the "Nobel Peace Prize for Physics". As opposed to the other physics prize?

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It's a fin thing

Apart from the convenience of researchers, film producers and beach wardens, why do sharks spend so much time displaying just their fins?

■ Very few species of shark make a habit of poking a dorsal fin out of the water. The main exception is the basking shark, which has a large dorsal fin and often swims close to the surface to feed on plankton. Other sharks show their fins rarely, and when they do, just like the basking shark, it is incidental to activity that brings them to the surface.

To describe exposing the fin as a "display" is misleading, because the shark is not doing it deliberately, any more than you "display" your foot to worms if you step into mud. The fin is simply appearing when the shark approaches the surface.

The dorsal fins of many sharks that swim constantly act as keels, helping to keep them upright and to provide control in high-speed turns. Most bottom-dwelling sharks don't need that kind of control, so many of them don't have conspicuous dorsal fins.
Jon Richfield
Somerset West, South Africa

■ Fin display is not a deliberate action, but a consequence of a shark putting its mouth and eyes where the food is – in this case near the surface. One other consideration is that surface water has a slightly higher oxygen level and is also slightly warmer, hence less dense, so this may also tempt sharks to the surface.
Andrew Doherty
Tongala, Victoria, Australia

■ Over the past 50 years, I have done more than 2000 ocean swims, totalling approximately 8000 kilometres. I occasionally see sharks, but I have never seen a shark with its fin out of the water.

It is worth noting one consequence of sharks spending a lot of time near the surface: they produce melanin and can develop a suntan. As for why people think sharks show their fins above the water a lot, there are two reasons. First, movies love to portray them this way because it is easy to make a fake shark fin, poke it out of the water and film it. It is much harder to make a realistic fake shark. Second, most people are at the surface when they see sharks, so inevitably only see them at this point. This is a form of availability bias, where we tend to think that what we see represents the general case when actually it probably isn't.
Stephen Johnson
Eugene, Oregon, US

It's a gas

Why are farts funny?

■ There are several reasons why flatulence puts a smile on some people's faces. The first is the relief felt by the farter as they get rid of troublesome bowel gas. The next is the sound of the fart as it announces its departure. This raises an air of expectation: will the fart be unscented or malodorous, and to what degree? This anticipation and associated humour seem proportional to the loudness and duration of the fart.

Farting's potential for humour peaks when there are more than two people in the room. A mischievous culprit can plead innocence and cause argument among the blameless.
David Muir
Edinburgh, UK

■ I was involved in a research project on the nature of humour a couple of years ago that found the answer.

Conventional wisdom says that laughter is triggered by the unexpected. But experiments in recent years showed this to be false: audiences laugh louder at surprise-free stories. To make someone laugh, you don't surprise them, you attack them.

If you are a comedian, you attack their conventions, their values, their assumptions, their expectations. If you are a parent, you physically "attack" your infants, nibbling them and throwing them in the air. This explains why you cannot tickle yourself: the sense of an external attacker is missing.

To fart in polite society is to attack multiple conventions, which is why some people find it funny. To maximise the laughter, choose a large audience and time it carefully. For example, wait for a school function during which the principal reads a poem that says: "And the Goddess Mother Nature released her mighty wind over the forest…"
Nury Vittachi
Hong Kong, China

■ Comical farting certainly has a history. Henry II of England, who ruled in the 12th century, once gave one of his minstrels a 12-hectare estate in Suffolk for performing the king's favourite party trick – a hop and a whistle, followed by a fart. The condition was that the minstrel, known as Roland le Fartere (what else?), had to do the trick every Christmas – and his descendants also had to carry on the tradition.

Fast-forward to France in the late 19th century, where Joseph Pujol, the French flatulist, or professional farter, used to amuse audiences by farting at will. He didn't actually pass intestinal wind, but could draw air in through the amazing control of his sphincter and then fart it out.
David Hulme
Stockport, Greater Manchester, UK

This week's question

TOWN OR COUNTRY?
Which lifestyle is better for my health: breathing plenty of fresh air in a dull, rural village, or never being short of mental stimulation by opting for life in a suburban metropolis with its polluted air?
Nathan Wheelhouse
By email, no address supplied

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