Turing's Legacy | Animals Race Against Climate | Beating Paralysis

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ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ JUNE 30, 2012

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Stone Age: The Movie

Taming PAIN

How to stop the body from crying wolf

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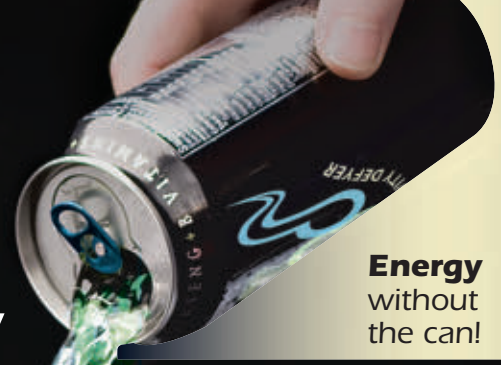

Energy without the can!

This is my story

I used to be more active. I used to run, play basketball, tennis; football… I

was more than a weekend warrior. I woke up every day filled with life! But now, in my late 30's, I spend most of my day in the office or sacked out in front of the TV. My energy has fizzled and I'm embarrassed to admit that I've grown a spare tire (I'm sure it's hurting my love life). Nowadays I rarely walk. For some reason it's just harder now. Gravity has done a job on me.

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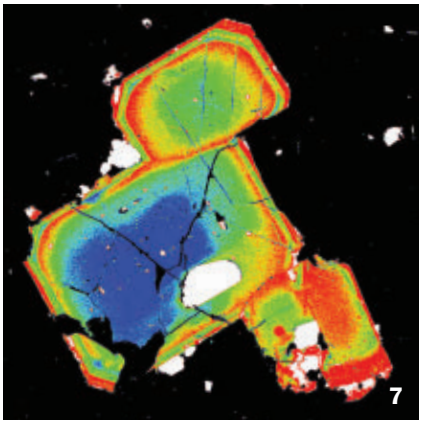

ScienceNews

In The News

Features

Essay

Departments

COVER When the pain system goes awry, nerves send erroneous signals to the brain even in the absence of a smarting stab. New work suggests a way to block such signals. *Michael Morgenstern*

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FROM THE EDITOR

Turing's idea still inspires advances in computing

Long before multigigabyte flash drives were cheaply available, evolution had bioengineered a pretty impressive storage device, now known as DNA. For eons, life has used DNA to store the information needed to make offspring from parents, and for cells to make the molecules required to meet the body's needs.

People have long exploited DNA's information for their own selfish reproductive purposes. And now scientists have figured out a new way to manipulate DNA memory, to compute in living cells. As Alexandra Witze reports (Page 14), new research shows how to store a bit of information in DNA and rewrite a new bit over it — just like computers do.

What a clever concept. Who would have thought that you could compute that way? Well, Alan Turing would have.

Turing, born a century ago this month, was the first to see how reading, erasing and rewriting bits enabled all sorts of computing tricks — in fact, all *possible* computing tricks. His 1936 paper, addressing a fundamental question in pure mathematics, perceived computation's very essence: writing and erasing 1s and 0s in response to a set of instructions.

In the new DNA system, instructions are provided by enzymes that cut and paste pieces of DNA in a bacterium; the 1s and 0s are signaled by whether a protein produced by the DNA glows red or green. In modern computers, instructions are encoded in programs (the software); 1s and 0s are represented by high or low voltages or other electronic and magnetic schemes in memory and processing chips (hardware).

This new biological form of computing and its analogy to the chips and programs of computers echoes Turing's original motivation in conceiving computing machines. As I write in this issue (Page 26), Turing imagined computing machines to be the analog of biological brains. He spoke of a computer changing its "state of mind" as it calculated by following the same instructions, or algorithms, that humans would use to solve a math problem. He foresaw the era of "intelligent" computers, something like today's talking smartphones, that interacted with humans in more ways than just mathematically.

Most of all, Turing's ideas helped reformulate the way people think about physical (and biological) reality. Analogies based on old machines, like clocks and steam engines and cars, don't capture the richness of real life. The universe and the living things within it are computational devices, churning out the future. And more life. —*Tom Siegfried, Editor in Chief*

JIM WEBB

How to Outsmart a Millionaire

Only the "Robin Hood of Watchmakers" can steal the spotlight from a luxury legend for under $200!

I wasn't looking for trouble. I sat in a café, sipping my espresso and enjoying the quiet. Then it got noisy. Mr. Bigshot rolled up in a roaring high-performance Italian sports car, dropping attitude like his $22,000 watch made it okay for him to be rude. That's when I decided to roll up my sleeves and teach him a lesson.

"Nice watch," I said, pointing to his and holding up mine. He nodded like we belonged to the same club. We did, but he literally paid 100 times more for his membership. Bigshot bragged about his five-figure purchase, a luxury heavyweight from the titan of high-priced timepieces. I told him that mine was the ***Stauer Corso, a 27-jewel automatic classic now available for only $179.*** And just like that, the man was at a loss for words.

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Say What?

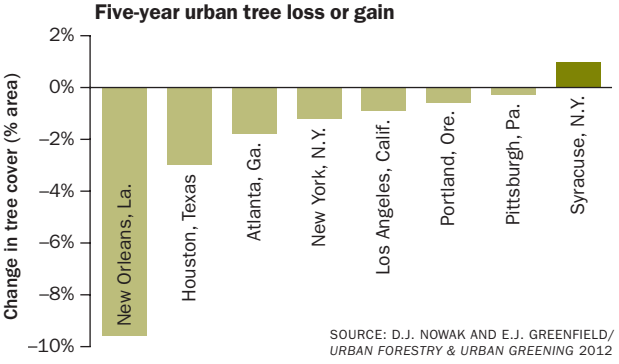
Voltinism *\VOL-ten-izm\ n.* The number of generations a species can produce in a year. Some insects can easily become grandparents or great-grandparents in that time, and rising global temperatures may give some species a longer reproductive season to spawn even more generations, Canadian researchers report in an upcoming *Global Change Biology*. The team used climate simulations to predict the effects of warmer temperatures on the voltinism of 13 agricultural pests in California, including the apple-eating codling moth (caterpillar stage shown). By the end of the century, the researchers say, 12 of those species could be pumping out one additional buggy generation per year in southern California. —*Allison Bohac*

Science Past | FROM THE ISSUE OF JUNE 30, 1962

JUST ADD WATER AND STIR TO USE INSTANT CHEESES — Instant cheddar and blue cheeses (add water and stir) will soon be on the grocer's shelf, adding to the growing list of compressed and condensed foods turned out by science.... For use in cheese sauces or sprinkled on pizzas, casseroles and other dishes needing the cheese touch, these two cheeses will soon be on the market, the American Dairy Science Association meeting at the University of Maryland, College Park, was told. The powdered cheese is made similarly to other dry milk products. Water is blended with plain cheese to make a liquid slurry, which is then homogenized. A heating process removes all water, leaving a uniform cheese powder, which can be reconstituted by the housewife.

Science Stats | CITIES LOSING SHADE

U.S. urban areas are losing about 4 million trees a year, the U.S. Forest Service reports. An analysis found declines in 17 out of 20 cities over five-year intervals since 2001, with the greatest loss in New Orleans due to Hurricane Katrina. Urban trees improve air and water quality and keep cities cooler, the researchers say.



SOURCE: D.J. NOWAK AND E.J. GREENFIELD/ *URBAN FORESTRY & URBAN GREENING* 2012

Science Future

July 13
Join the New York City Bat Group for a dusk bat walk in Central Park. Bat watchers collect data used to monitor the city's bat population. See bit.ly/SFbatwalk

July 15–August 5
Summer Sundays at the Brookhaven National Lab in New York invite the public into the facility for tours, speakers and science activities. Learn more at 1.usa.gov/SFbnlsun

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SCIENCE & SOCIETY
Science knowledge tends to bolster existing views. See "Climate skepticism not rooted in science illiteracy."

ENVIRONMENT
Irrigation may be responsible for a third of today's sea-level rise. Learn more in "Pumping groundwater raises sea level."

HUMANS
People all use similar language rules to label kin. Read "Family labels framed similarly across cultures."

An ancient culture dries out in "Harappans may have lived, died by monsoon."

Introducing | YOU SAY TOMATO, I SAY A, G, C, T ...

The chemical letters that make up the DNA of tomatoes, specifically the kind of tomato inside Heinz ketchup bottles, have been spelled out for the first time. Researchers from the Tomato Genome Consortium spent nine years piecing together the genetic blueprint of the breed Heinz 1706. A nearly complete letter sequence for the domesticated plant — reported in the May 31 *Nature* alongside a draft for the wild *Solanum pimpinellifolium* (shown below) — shows that the tomato copied its full set of genes in triplicate twice during its evolution, leaving it with more genes than humans have. Some of the gene copies changed over time, giving rise to the redness and fleshiness prized in tomatoes today. Having the tomato's genetic instruction manual in hand could help breeders further tweak the fruit, changing the DNA that will eventually line your great-grandchildren's ballpark franks. —*Devin Powell*

CLOCKWISE FROM TOP LEFT: PEGGY GREB/WIKIMEDIA COMMONS; CINOBY/ISTOCKPHOTO; MIXA/GETTY IMAGES

“These elderly odors were very distinct and easy to group together.” —JOHAN LUNDSTRÖM, PAGE 8

In the News

STORY ONE

Treatment helps paralyzed rats walk, run, climb

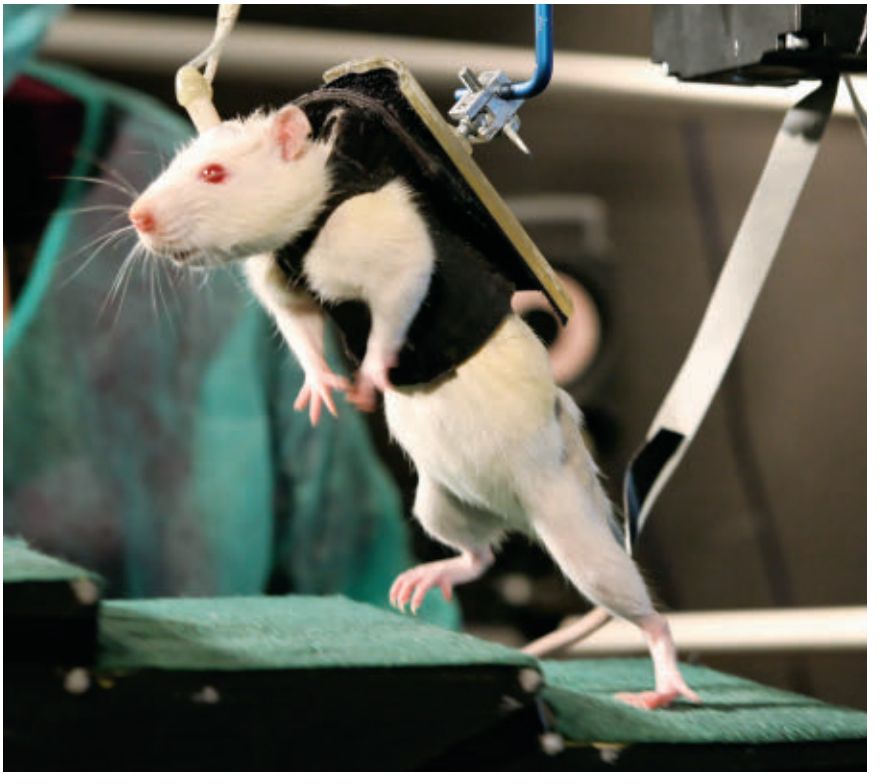
Drugs, shocks and therapy trigger new nerve growth

By Laura Sanders

Scientists have trained paralyzed rats to walk, run and even climb stairs. Weeks of rigorous practice coupled with an electrochemical spine-stimulating regimen allowed the animals to overcome devastating spinal cord injuries that immobilized their rear legs, Swiss scientists report in the June 1 *Science*.

Although preliminary, the results offer hope to people paralyzed by spinal cord injuries. “The really exciting thing, the take-home message for people living with spinal cord injuries, is that this represents yet another step towards real treatment,” says neurologist John McDonald of the Kennedy Krieger Institute in Baltimore and the Johns Hopkins University School of Medicine. “The real beauty is that this is not something that would necessarily have to go through 10 years of FDA approval.”

Recovery, the Swiss team found, relied on a combination of treatments, all readily adaptable to humans: Nerve cells in the spine below the damaged site were stimulated with a cocktail of drugs similar to some antidepressants. Electrical shocks, delivered via electrodes, also activated the spinal cord. In this way, the researchers primed the rats for the next stage of treatment — learning to walk again.



COURTESY OF EPFL

Motivated by treats, previously paralyzed rats were able to walk, run and even climb stairs after treatment with a nerve-activating drug cocktail, electrical stimulation and a physical therapy regimen involving a robotic harness.

A stabilizing robotic harness held each treated rat upright on its hind legs and kept it from tipping over sideways, a device that study coauthor Grégoire Courtine of the Swiss Federal Institute of Technology in Lausanne likens to two very strong physical therapists. The animals were then tempted with cheese and chocolate — a situation that drove the rats to try very hard to move forward.

“The brain is maximally engaged and willing to do anything to reach its reward,” says Courtine.

After several weeks of training, the formerly paralyzed rats began taking voluntary steps toward their treats. Astonished, Courtine says, he and his colleagues kept pushing the rats to do more and more sophisticated voluntary movements. More training allowed the animals to run, climb stairs and avoid obstacles in their paths. Stronger animals were even able to bear their entire body weight on their two back legs.

It turns out that motivation is crucial, and not just because the obstacles are so great. Prompted by a moving treadmill, rats that received the electrochemical

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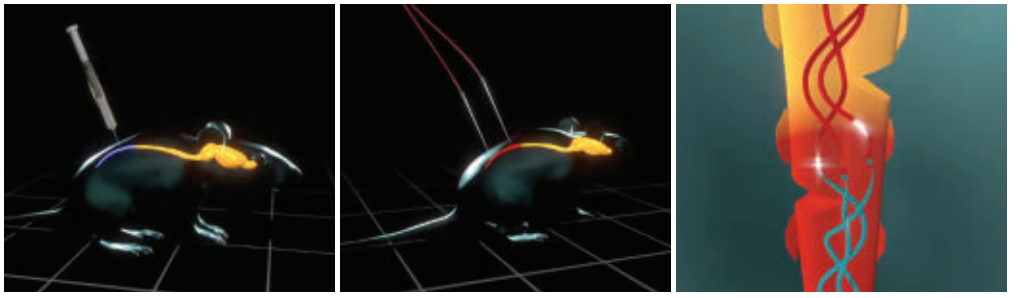


After therapy with drugs (left), electrical stimulation (center) and training, paralyzed rats' nerve fibers sprouted, bypassing the original spinal injury site (right) and reconnecting the spinal cord with the brain.

treatment could put one foot in front of the other, but this kind of movement was automatic and didn't involve the brain. Rats could walk voluntarily only when the training included the motivating treat.

Experiments on the animals' brains and spinal cords revealed that the nervous system had rewired itself in many different ways by sprouting detours around the injury site. Actively trained rats had new nerve fibers running from the brain down to the spinal cord. These rats also had changes far away from the injury site in the motor cortex, the part of the brain that controls leg movements. The brains of rats trained only on treadmills showed no changes.

The finding fits with a growing realization that active rehabilitation — in which a person is maximally engaged and electrodes stimulate paralyzed muscles — works, McDonald says. McDonald used similar techniques to help actor Christopher Reeve regain some voluntary control over select muscles years after a spinal cord injury left him paralyzed.

Most spinal cord injuries in people result from severe bruising, which can leave some remaining tissue to bridge the spinal cord to the brain. The Swiss team studied rats with two staggered, incomplete snips to their spinal cords, which completely paralyzed the animals' hind legs but also left an island of intact spinal cord tissue between the damage sites and the brain.

The study raises some questions, such as whether the technique will work for the more common kind of bruise-induced injury, which is less orderly than the rats' injury. Also unclear is whether other movements would show a similar improvement. Fine hand or finger control, for instance, might require a different kind of training regimen, says neuroscientist Michael Beattie of the University of California, San Francisco. Balance may also require a different kind of training. Some of the more successful rats were able to walk a few steps on four legs, but quickly lost balance and fell over without the supportive harness.

The Swiss team's success supports a more principled approach to treating spinal cord injuries, Beattie says. "Most rehabilitation is done by, 'This should work.' There's not a lot of evidence-based practice," he says. The new study, he says, and others like it can help scientists understand how rehabilitation can be optimized. "It may be that people with severe injuries, if they get the right kind of treatment, can perform much better than we thought."

Courtine and his colleagues are continuing to test their method. Preliminary results suggest that spinal cord–stimulating drugs can be progressively tapered with no loss of benefits. And as part of a project called NeuWalk, Courtine and his colleagues are developing an electrical stimulator for humans. The team hopes to get safety approval for that device in the next two years. ■

Back Story | A STEP FORWARD

In the summer of 2006, college pitcher Rob Summers was in peak physical condition, hurling 90-mile-per-hour fastballs, mean cutters and particularly devastating curve balls in preparation for the baseball season at Oregon State University. But this plan veered off course when a hit-and-run accident left him paralyzed below the chest. After years of intense physical therapy, Summers qualified to take part in an experimental treatment: Doctors surgically inserted an epidural stimulator onto his spine. The device electrically activates nerve cells in the spinal cord — a therapy similar to part of the approach described in the new rat study. With the stimulator on, Summers (shown training at left) was able to stand up independently, wiggle his toes, ankles, knees and hips, and walk with assistance on a treadmill. His success was reported in the *Lancet* in 2011.
— Laura Sanders

FROM TOP: COURTESY OF EPFL; ROB SUMMERS

Earth

580 cubic km | Volume of Long Valley supereruption, 760,000 years ago

2,450 cubic km | Volume of Yellowstone supereruption, 2.1 million years ago

Supervolcanoes evolve superfast

Magma chambers form in less time than previously thought

By Alexandra Witze

Earth's biggest eruptions may happen faster than volcanologists had thought. Giant blobs of magma appear underground and then pour onto the surface within centuries, suggests a new study of a California supereruption.

California's Long Valley was formed after a supervolcano exploded 760,000 years ago. Quartz grains in rocks suggest the magma chamber beneath the eruption was there only briefly.

If true for other volcanoes, the work means the most powerful eruptions don't have magma chambers beneath them for very long. So if big changes start happening, like ground rising or new geysers spouting, volcanologists might expect an eruption sooner rather than later. Yellowstone, for one, underwent its most recent supereruption about 640,000 years ago.

"The fact that at Yellowstone there's no giant magma body right now doesn't mean that in hundreds to thousands of years we couldn't have one," says geologist Guilherme Gualda of Vanderbilt University. "By understanding these timescales better, we know better what to expect." Gualda and colleagues report the discovery May 30 in *PLoS ONE*.

The team studied 760,000-year-old rocks, known as the Bishop Tuff, from Long Valley in eastern California. These rocks formed during one of the biggest eruptions known; it spread nearly 600 cubic kilometers of ash and other debris across the landscape. Earlier studies, looking at crystals such as zircon, suggested that the Bishop magma sat underground chemically evolving and slowly crystallizing for more than 100,000 years.

Gualda's team looked instead at crystals of quartz. Certain properties of the quartz—such as to what extent the element titanium migrated within it—can indicate how long ago the quartz solidified. That process would begin almost as soon as the magma body appears, the researchers' calculations showed. Once quartz forms, gas pressure builds up and eventually forces the magma to erupt.

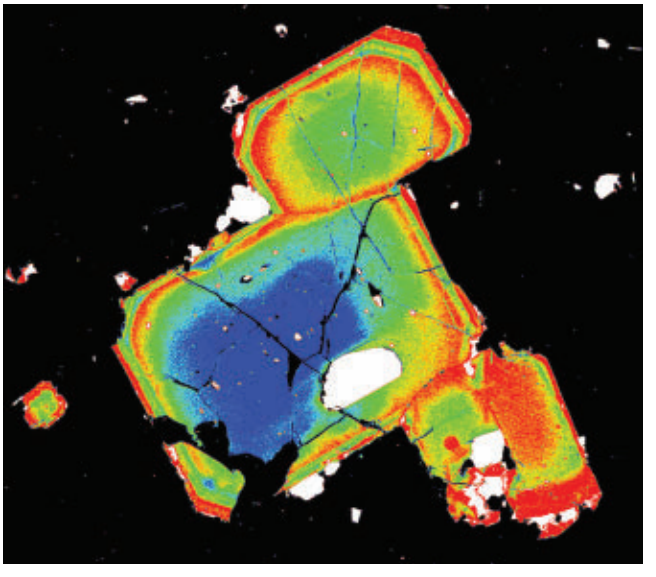
Bishop Tuff quartz would probably have crystallized 500 to 3,000 years before the Long Valley eruption, the team reports. Past studies with zircon finding a much older age may represent a longer-term history of volcanism across the entire region, Gualda says.

The new discovery supports the idea that magma can accumulate rapidly before supereruptions, says Erik Klemetti, a geologist at Denison University in Granville, Ohio, who has found similar rapid changes in zircon crystals from New Zealand eruptions. Still, he says, "this study really doesn't address a key question—just how do these large magma bodies initially form?"

For now, Gualda is leaving that challenge to others. He is working to apply the new finding to other supervolcanoes to see whether they play by the same rules as Long Valley.

Linking magma to quakes

Active volcanoes shake, rattle and roll; scientists can't always be sure whether such activity indicates that molten rock is rising. Now, volcanologists have linked earthquake swarms at Mount St. Helens in Washington state with fresh magma pulses. A team led by Kate Saunders of the University of Bristol in England studied more than 300 rock crystals formed during the 1980–1986 eruption of Mount St. Helens. These crystals (one shown), of a mineral called orthopyroxene, grow in zoned "rims," each formed as fresh magma arrives from below and cools. Saunders' team calculated when the crystals grew and compared that with the timing of small earthquakes shaking the mountain. In many cases the crystal rim growth and seismic swarms matched, the team reports in the May 25 *Science*. Studying crystals erupted from other volcanoes could help scientists better understand how often new magma arrives, Saunders says. —*Alexandra Witze*



FROM TOP: G. GUALDA/VANDERBILT UNIV.; K. SAUNDERS/UNIV. OF BRISTOL

Body & Brain

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Drinking coffee gives jolt to life span

Java linked to slightly increased longevity, reduced disease

By Nathan Seppa

It's the news that coffee addicts have been waiting for: Drinking several cups of coffee every day may help you live longer. A study of more than 400,000 people finds that drinking coffee may reduce the risk of death from heart disease, lung disease and even infections, researchers report in the May 17 *New England Journal of Medicine*.

Scientists have puzzled over the notion that a stimulant could provide a health benefit. "Our results might provide some reassurance for long-term coffee drinkers," says study coauthor Neal Freedman, an epidemiologist at the National Cancer Institute in Bethesda, Md.

The research has the limitation of being observational in nature. But with data from 402,260 participants, the results are "very powerful" and unlikely to be superseded by another coffee study anytime soon, says Roy Ziegelstein, a cardiologist at the Johns Hopkins Bayview Medical Center in Baltimore.

Freedman and his colleagues analyzed responses to a detailed questionnaire that included questions about coffee intake. The researchers excluded people who had previously had cancer, heart disease or some other serious illness and recorded the remaining volunteers' mortality status through 2008 by checking death records. Researchers accounted for differences such as body mass, smoking status and diet.

> "Our results might provide some reassurance for long-term coffee drinkers."
> NEAL FREEDMAN

After a median of 13.6 years, people who drank two or more cups of coffee per day were 10 to 16 percent less likely to have died than nondrinkers. A single cup a day provided less apparent benefit. Women who drank six cups of coffee per day or more had a 15 percent reduced risk of death compared with nondrinkers, while men consuming that much had only a 10 percent reduced risk.

More than two cups a day seemed to offer some protection against death due to heart disease, respiratory ailments and diabetes, while four or more cups a day imparted apparent benefits against infections.

Caffeine may not play a big role in coffee's apparent benefit. Decaffeinated coffee consumption was associated with about the same longevity edge as regular. "Given that the relationship between coffee intake and reduced mortality is not confined to one particular disease suggests that there are a lot of possible mechanisms involved," says epidemiologist Rachel Huxley of the University of Minnesota in Minneapolis.

Youngsters can sniff out elderly

Evaluators describe scent as 'earthy' and 'mild'

By Rachel Ehrenberg

"Old people smell" is for real — and it isn't mothballs, Jean Naté or pipe tobacco. It's a mild and not unpleasant odor compared with the intense, unpleasant smell emitted by 40- to 50-something guys, a new study finds.

Scientists don't know what makes up the vintage chemical fingerprint, but the negative association with the smell of the elderly appears to be more about context than scent, says Johan Lundström of the Monell Chemical Senses Center in Philadelphia.

Lundström and colleagues collected underarm odors from 12 to 16 people in each of three age groups: young (20 to 30 years old), middle-aged (45 to 55 years old) and old (75 to 95 years old). For five nights while they slept, study participants wore T-shirts with breast-feeding pads sewn in the underarms. The shirts and bed linens had been washed with scent-free soap and the participants did the same to themselves before going to bed each night. They refrained from smoking, drinking alcohol or eating foods known to contribute odors to bodily secretions.

Evaluators (ages 20 to 30) then sniffed the armpit pads, rating the samples on pleasantness and intensity, and guessing which of two odors came from the older donor. The evaluators had trouble discerning young from middle-aged odors. But the odors from old donors were correctly identified more often than would be expected by chance, the research team reports online May 30 in *PLoS ONE*.

"These elderly odors were very distinct and easy to group together," says Lundström. Odors from old men were rated most pleasant among males, especially compared with middle-aged men. (Middle-aged woman odors were rated more pleasant than elderly woman odors.)

And descriptions of the elderly odors weren't negative: Evaluators used phrases such as "earthy" or "mild, like stale water," Lundström says.

"Everything changes with age, so it's not a huge surprise," says Dustin Penn, who heads the Konrad Lorenz Institute of Ethology in Vienna.

The possible mechanisms behind bodily bouquets are most intriguing, he says. Perhaps the drop in testosterone that occurs in old age makes the older scents discernible. Work by Penn and others suggests that a person's microflora also contributes to Eau de You.

"As a doctor, if you had a drug for cancer ... that was 20-fold better than the next drug, you would never [prescribe] that other drug." —JEFFREY PEIPERT

Severe apnea tied to cancer

Study finds oxygen loss from sleep disruption raises risk

By Nathan Seppa

Obstructive sleep apnea, a breathing disorder linked to heart disease and depression, may heighten the risk of cancer as well. A two-decade study shows that people with severe sleep apnea could be four times as likely to die of cancer as people without the condition.

"This is a kind of study that provides the opportunity to look at the long-range consequences of sleep apnea," says Jonathan Samet, a pulmonary physician at the University of Southern California. "What's surprising is the strength of the association they found."

The findings were unveiled May 20 in San Francisco at a meeting of the American Thoracic Society and published online in the *American Journal of Respiratory and Critical Care Medicine*.

Sleep apnea occurs when a flap of skin in the throat obstructs air intake, often due to obesity, halting breathing during sleep for at least 10 seconds at a time. Severe apnea is marked by frequent breathing stoppages that cause a person to gasp for air. What's more, the disruptions rob cells of needed oxygen, a condition called hypoxia. This may underlie the cancer link, says study coauthor Javier Nieto, a physician and epidemiologist at the University of Wisconsin–Madison.

Nieto and colleagues investigated cancer among 1,522 participants in a sleep study that began in 1988. Tests showed that 59 people had severe sleep apnea from the get-go. By November 2011, those with severe apnea were 4.8 times as likely to have died of a cancer-related cause.

Readings taken at the outset of the original sleep study allowed the researchers to measure how much of the night each volunteer had spent in an oxygen-deficient state. Even after adjusting for other risk factors, those with the most severe hypoxia were nearly nine times as likely to have died of cancer during the ensuing study year.

Long-acting contraceptives best

Implants, IUDs outperform pill and other birth control options

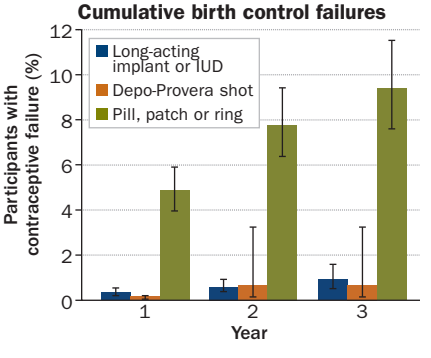
By Nathan Seppa

Long-acting birth control devices are nearly 22 times as reliable as contraceptive pills or other short-acting approaches that need close monitoring, a new study shows. Since about half of all unplanned pregnancies are traceable to failed birth control, switching to a long-term, reversible contraceptive could prevent many accidental pregnancies, researchers say.

"As a doctor, if you had a drug for cancer or hypertension that was 20-fold better than the next drug, you would never write [a prescription] for that other drug," says study coauthor Jeffrey Peipert of Washington University in St. Louis. "We hope that clinicians will rethink what is standard practice — that a young woman comes in and gets pills or condom counseling. We have methods that are much, much better."

The findings also hint that if cost were not an issue, most women given a choice of common hormone-based contraceptives would prefer the long-acting devices. About 77 percent of the women who volunteered for the study chose an intrauterine device or a small implant placed under the skin. Only 20 percent requested shorter-acting options such as the pill, a vaginal ring or a skin patch. Fewer opted for hormone injections called Depo-Provera. All costs were covered by the study, appearing in the May 24 *New England Journal of Medicine*.

Low-risk, high-risk During a three-year study, the percentage of women using a contraceptive who became pregnant was lower for those using long-acting methods. Highest rates occurred for birth control pills, a skin patch or a vaginal ring. SOURCE: B. WINNER *ET AL*/*NEJM* 2012



"This study brought home how big a difference there is between effective methods and *really* effective methods" of contraception, and comes at a time when demand for birth control is growing, says Lawrence Finer, a public health researcher at Columbia University. The point at which women are getting married and giving birth is getting later, he says. "But the age at first sex hasn't changed that much. You've got a long period where people need contraception."

The researchers monitored 7,486 girls and women given the hormonal contraceptive of their choice. (The researchers didn't offer barrier devices such as condoms or diaphragms.) During three years of follow-up, there were 156 unintended pregnancies attributable to contraceptive failure. The pill/patch/ring group had failure rates of 4.8 percent after the first year and 9.4 percent after the third year. Long-term devices and injections had failure rates of less than 1 percent.

Teenagers have a lot to gain from long-acting devices, since their record of adhering to daily birth control is inconsistent, says James Trussell, a public health researcher at Princeton University.

53 milliseconds | Half-life of livermorium-293

510 milliseconds | Half-life of flerovium-287

Quantum teleportation takes leap

Two teams improve long-distance information transmission

By Alexandra Witze

Quantum information has leapt through the air about 100 kilometers or more in two new experiments, farther and with greater fidelity than ever before. The research brings true long-distance quantum communication networks, in which satellites could beam encrypted information around the globe, closer to reality.

Both studies involve quantum teleportation, which transports the quantum state of one particle onto another. This *Star Trek*–like feat is possible because of a phenomenon called entanglement, in which pairs of particles become linked in such a way that measuring a certain property of one instantly determines the same property for the other, even if separated by large distances.

In teleportation, two people — physicists call them Alice and Bob — share one each of a pair of entangled particles. Alice measures a property on her particle and sends Bob a note, through regular channels, about what she did. Bob then knows how to alter his own particle to match Alice's. Bob's particle then possesses the information that had been contained in Alice's, which was obliterated by her measurement. Thus the information has been "teleported" from Alice's lab to Bob's.

Physicists first teleported quantum information in 1997 using a single pair of entangled photons, or particles of light. Since then researchers have teleported larger groups of photons over longer distances.

In 2007 Anton Zeilinger of the University of Vienna and colleagues set a distance record by using a pair of entangled photons to transmit quantum information over 143 kilometers, between two of the Canary Islands. In new work, posted online May 17 at arXiv.org, the team reports a cleaner and more robust version of the same experiment, using multiple photons.

> "Our experiment ... is a milestone towards future satellite-based quantum teleportation."

This time, the scientists added a phase shift into the laser beams that made the final measurement cleaner and easier to pick out from background signals. The technique, called "active feed-forward," is "an essential ingredient in future applications such as communication between quantum computers," Zeilinger and colleagues wrote. Team members declined interviews because the paper is not yet published in a peer-reviewed journal.

"Our experiment confirms the maturity and applicability of the involved technologies in real-world scenarios, and is a milestone towards future satellite-based quantum teleportation," they wrote.

In another experiment, Chinese scientists entangled many photons and teleported information 97 kilometers across a lake in China. That's two orders of magnitude farther than any other multiphoton teleportation, say Jian-Wei Pan of the University of Science and Technology of China in Hefei and colleagues. Their work appeared online May 9 on arXiv.org.

Pan's team also found a way to track teleportation signals more accurately to make results more robust. "Our results show that even with high-loss ground to satellite uplink channels, quantum teleportation can be realized," the scientists write.

Both teams next want to teleport to a satellite in low Earth orbit — about three times as far as the distance between the two Canary Islands. But because there are fewer air molecules at higher altitudes, it may be easier to do. ■

Meet flerovium and livermorium

Group confers official names on two superheavy elements

By Alexandra Witze

Two labs and longtime partners in creating synthetic superheavy chemical elements have been honored by new names for two of them. Element number 114 is now officially known as flerovium (symbol Fl), after the Flerov Laboratory of Nuclear Reactions in Russia. And element 116 is now livermorium (Lv), after the Lawrence Livermore National Laboratory in California.

The International Union of Pure and Applied Chemistry will publish the new names in the July issue of *Pure and Applied Chemistry*.

The elements were created at the Flerov lab in Dubna, Russia, in 1998 (flerovium) and 2000 (livermorium) by hurling calcium ions, with 20 protons each, into a piece of curium, which has 96 protons. That merger made element 116, which decayed almost immediately into element 114 and then into lighter elements. Element 114 was also created by colliding calcium with plutonium, element 94.

The naming of superheavy elements is often a battle for prestige over who should get credit for the discovery. But both elements were discovered by a Flerov/Livermore collaboration, and IUPAC agreed with the labs' proposal that each should be honored.

Still awaiting formal names are elements 113, 115, 117 and 118. Researchers are hoping to synthesize even heavier elements that might occupy an "island of stability" where the elements stick around for longer instead of decaying very rapidly. ■

Atom & Cosmos

Second planet takes spotlight

Astronomers watch Venus pass across face of the sun

By Nadia Drake

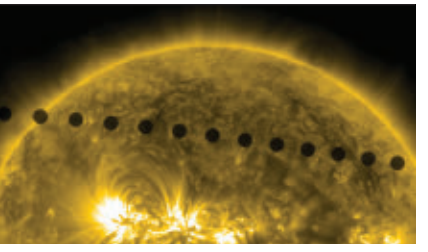
On June 5 and 6, millions of skywatchers came out to glimpse the last transit of Venus visible from Earth for more than a century. During a six-hour journey in which the planet passed directly between Earth and the sun, Venus appeared as an inky black dot in silhouette against the looming solar disk.

The rare alignment of Earth, its sister planet and star most recently occurred in 2004 and won't happen again until 2117. Because Venus' orbit is slightly off-kilter, its solar transits come in pairs spaced eight years apart, with more than 100 years between pairs. (The last transit pair took place in 1874 and 1882.)

Measurements of this year's transit will reveal more not only about Venus itself, but also may inform observations of far-off exoplanets that similarly betray their presence by passing between their star and Earth.

In an effort to assemble the most complete observation of Venus' backlit atmosphere, scientists deployed nine instruments to far-flung locales. During the transit, the sun illuminated Venus' upper atmosphere, providing information about temperature and aerosols across the planet. The *Venus Express* spacecraft, currently orbiting the planet, can gather data only about isolated portions of the swirling sulfuric acid clouds. Scientists hope the new data will shed light on how the shroud behaves globally.

Astronomers have been able to study the atmospheres of Jupiter-sized exoplanets in transit, but similar observations of terrestrial exoplanets have yet to be done. Gathering data about a known planet — Venus — will help ground those future observations, says astronomer Paolo Tanga at the Cote d'Azur Observatory in Nice, France. "Maybe one day we will be able to measure the same light that is filtered from the atmospheres of exoplanets — exo-Venuses and exo-Earths," says Tanga.



NASA's Solar Dynamics Observatory had a front-row seat for the June 5 transit of Venus (montage in extreme UV light shown) across the sun's face.

SDO/GSFC/NASA

Humans

"They really take a philosophical theory and make it an experiment." —MARCO IACOBONI

Stone Age artists produced movies

Cave paintings, artifacts create illusion of animals in motion

By Bruce Bower

By about 30,000 years ago, Europeans were using cartoonlike techniques to give the impression that lions and other wild beasts were charging across cave walls, two French investigators find.

Artists created graphic stories in caves and illusions of moving animals on rotating bone disks, say archaeologist Marc Azéma of the University of Toulouse–Le Mirail in France and Florent Rivère, an independent artist based in Foix, France.

Azéma and Rivère summarize their 20 years of research on Stone Age animation techniques, much of it previously published in French, in the June *Antiquity*. They also describe for the first time examples of animation at two French caves, Chauvet and La Baume Latrone.

"Movement and action are indeed represented in cave art in different manners," remarks archaeologist Jean Clottes, honorary conservator general of heritage for the French Ministry of Culture. Clottes led a 1998 investigation of Chauvet's 30,000-year-old cave paintings.

A 10-meter-long Chauvet painting represents a hunting story, Azéma proposes. The story begins by showing several lions, ears back and heads lowered, stalking prey. Mammoths and other animals appear nearby. In a second section of the painting, a pride of 16 lions, some drawn smaller than the rest to appear farther away, lunge toward fleeing bison.

Ancient artists created bone toys inscribed with figures of an animal on either side. When strung on an animal tendon and spun, the toys depict the animal moving.

Artists meant to depict movement in such scenes, Azéma says. An eight-legged bison at Chauvet, for example, resulted from superimposing two images of the creature in different stances to create the appearance of running. Flickering torches passed over painted scenes would have heightened onlookers' sense of seeing live-action stories.

Ancient Europeans also invented a kind of animation toy. Sites in France and Spain have yielded stone and bone disks and plaques, typically with center holes, showing opposing images of sitting and standing animals.

In experiments, Rivère has reproduced these disks and looped strands of animal tendon through the center holes. By twisting these strands, the disks rotate back and forth rapidly enough to make animals appear to be sitting down and standing up.

Thou just can't help but covet

Wanting what others have may be hardwired in brain

By Laura Sanders

As every kid knows, the very best toy is the one that someone else is playing with. A new study on covetous adults explains why other people's possessions always seem better.

Seeds of this desire are sown in the mirror neuron system, a part of the brain that is activated in a similar pattern whether a person is performing an action or merely watching someone else do it.

Envy can spread among people like a disease, a force that explains much of human behavior, French philosopher René Girard proposed in the 1980s. Now, French neuroscientists have verified the phenomenon and even attempted to explain how it happens.

"They really take a philosophical theory and make it an experiment," says neuroscientist Marco Iacoboni of UCLA.

Copying other people's desires is a good way to learn about the environment, says study coauthor Mathias Pessiglione of INSERM in Paris. Eating what other people eat, for example, is a simple way to avoid food poisoning. But this adaptive feature can break down when desired objects are in short supply.

Pessiglione and his team showed adults one of two videos: a piece of candy sitting on a surface or a person's hand reaching toward a different-colored piece of candy. Participants then rated the desirability of each candy they saw.

People rated the about-to-get-grabbed candy as more desirable. The same effect held for clothes, tools and even toys, the team reports in the May 23 *Journal of Neuroscience*.

Brain scans revealed that two systems are behind the phenomenon. First, activity increased in the parietal lobe and the premotor cortex, parts of the brain's mirror neuron system . Second, the parts of the brain involved with deciding how much objects are worth — the ventral striatum and the ventromedial prefrontal cortex — got busy.

These two systems are linked, so that the mirror neuron system kicks on and tells the brain's valuation system to rank the object highly, the team's analyses of the brain scans suggest.

M. AZÉMA, J. CLOTTES, CHAUVET CAVE SCIENTIFIC TEAM

Life

1.5 days/decade | Advance in annual arrival of male broad-tailed hummingbirds since 1970s

4.6 days/decade | Advance in annual flowering of glacier lilies since 1970s

Bad timing for hummingbirds

Warming reduces time for males to find breeding spots

By Susan Milius

Throughout the world, climate change is causing age-old ecological partners to miss their cues as seasons shift (see Page 16). The trend may be so strong at higher latitudes that researchers now propose that some species' ranges could actually shrink away from the poles.

This idea comes from studying broad-tailed hummingbirds that migrate north from Central America each spring to high-altitude breeding sites in the western United States. With only brief summers to raise chicks, male hummingbirds typically arrive in the region to scout for territories before the first flowers bloom.

Around Rocky Mountain Biological Laboratory in Gothic, Colo., near the northern limit of the birds' breeding range, the gap between first hummingbird arrival and first bloom has narrowed by roughly 13 days during the last four decades, Amy McKinney of the University of Maryland in College Park and colleagues report online May 14 in *Ecology*.

Glacier lilies start blooming roughly 17 days earlier than they did in the 1970s, but birds haven't sped up nearly as much. In a few extreme years, lilies have bloomed before the first hummingbird showed up. If the trends continue, in about two more decades the males will routinely miss the first flowers.

Other flowers bloom all summer, but losing the start of the flowering season cuts into an already tight breeding schedule. Around the Rocky Mountain laboratory, broad-tailed hummingbird pairs have time to raise only one brood of at most two chicks per summer.

If shifts in available flowers end up hampering efforts to raise chicks, then this northerly zone of current breeding territory may someday dwindle away.

Such timing mismatches are probably very common, says evolutionary ecologist Marcel Visser of the Netherlands Institute of Ecology in Wageningen. He has documented difficulties with the spring return of migratory European birds called pied flycatchers that have been outpaced by earlier peaks of caterpillars that would once have fed the chicks.

Some broad-tailed hummingbirds that breed farther south have less of a problem. By pooling decades of data collected for various projects, McKinney and colleagues compared timing on the north rim of the birds' breeding range with almost 30 years of bloom and bird records in Arizona, where there's no clear narrowing of the gap between male bird arrival and first blooms of an Indian paintbrush that starts the nectar season.

Ecologist Anthony Richardson says he's not yet convinced that higher latitudes on land see more dramatic changes in timing of biological events. Marine trends seem to lessen with increasing latitude, reports Richardson, of the University of Queensland in St. Lucia, Australia.

Climate change is making it harder for male broad-tailed hummingbirds to scout for territory in summer breeding grounds before flowers start blooming.

FROM TOP: DAVID INOUYE; BLACK NODDIES: TOMMY ADKINS; MANTA RAY AND ATOLL: KYDD POLLOCK

Trickle-down ecology

By following a cascade of ecological consequences, researchers have traced the influences of preserving bird-friendly native forests versus planting replacement coconut palms on the Pacific atoll of Palmyra (bottom). Red-footed boobies, black noddies (top left) and other seabirds that feast on fish nest in Palmyra's sturdy, many-branched native trees, says ecologist Douglas McCauley of the University of California, Berkeley. The birds tend to avoid the branch-poor, bendy coconut palms planted by people. It turns out that the birds' real estate decisions affect where big fish feed off the coast. The nesting seabirds enrich forest soil with their droppings and carcasses; water washing out of this forest carries about 26 times as much nitrogen as runoff from palm plantings. Tiny plankton in the sea flourish on nitrogen, so plankton-feeding giant manta rays (top right) prefer waters near native forests instead of near the coconut groves, McCauley and colleagues report online May 17 in *Scientific Reports*. —*Susan Milius*

Genes & Cells

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DNA stores data in rewritable form

Genetically encoded memory allows computing inside cells

By Alexandra Witze

They aren't yet competition for Intel, but bioengineers have created a one-bit "memory" made of DNA that can record, erase and rewrite data within living cells.

One day, doctors might be able to insert such devices into a cancer patient to tally how many times a cell divides and flag malignant growth. Or researchers might track exactly what happens inside cells as they age. The work is an advance in synthetic biology, a field in which scientists create tools to control life's basics from the cell on up.

"We can write and erase DNA in a living cell," says bioengineer Jerome Bonnet of Stanford University. "Now we can bring logic and computation inside a cell itself."

Bonnet and colleagues, led by Stanford's Drew Endy, describe the feat online May 21 in the *Proceedings of the National Academy of Sciences*.

Scientists have long dreamed of putting tiny computers inside the body to monitor or even control what's going on. But nobody has made a silicon-based computer chip small enough to embark on a fantastic computing voyage inside a cell.

So researchers are turning instead to biological tools, such as enzymes and DNA. Some biologists have devised DNA switches that can be turned on and off within a cell. And in 2009, bioengineers reported making a genetic "counter" that could tally the number of times a particular event, like a cell dividing, took place.

But these previous efforts made systems that could write a piece of information only once. Truly useful digital data storage allows information to be erased and rewritten over and over, like burning new data onto a CD. "What we didn't have is some kind of logic that also has memory," says Pakpoom Subsoontorn, a graduate student on the team.

The scientists chose DNA for memory, using enzymes called recombinases as the tools to flip it on and off. Those enzymes came from bacteriophages, viruses that infect bacteria. These viruses use one enzyme to integrate into the genome of the bacterium they're infecting.

In the experiment, the enzyme traveled to a particular place on the DNA that contains genetic information and flipped a small section so that it read backward. Sending a second signal flipped the DNA back to its original state. The flipped and unflipped versions represent the "0" and "1" states of a computer bit, says Bonnet.

Working in the bacterium *Escherichia coli*, the team also tweaked the DNA so that it would fluoresce in different colors depending on the orientation of the strand in question. By watching the cells' glow change between red and green and then back again, the scientists could tell when the DNA strand had been flipped.

So far, Endy's team has just one bit of memory. The researchers hope to scale up to eight bits, or a byte — a goal that could take many more years, Bonnet says.

But the team has now gotten the flips to hold for more than 100 generations within a living cell, a laboratory first. "This was an important proof of concept that it was doable," says Bonnet. "Now we want to build a more complex system, something other people can use."

Though interesting, it's not clear that DNA-based memory will ever replace silicon-based memory for most uses, says Roger Brent of the Fred Hutchinson Cancer Research Center in Seattle. ■

CAROL WALKER

10 genes for poppy potion

Opium poppies, such as the Tasmanian flowers pictured here, are prized for the valuable drugs they produce. Scientists have long known how the plants make opiates such as codeine and morphine, but the molecular steps the plants use to make a nonaddictive substance called noscapine have been a mystery until now. Noscapine is a cough suppressant that is also used as an antitumor drug. A group of 10 genes carries the instructions for building the enzymes that *Papaver somniferum* plants use to produce noscapine, Ian Graham of the University of York in England and colleagues report online May 31 in *Science*. Poppies with two copies of each of the noscapine-producing genes make high levels of the drug, while poppies that inherit only one copy of the genes make less noscapine. Poppies that lack the genes make none of the drug. The discovery could make it easier for drug companies to manufacture noscapine. —*Tina Hesman Saey*

Technology

Bacterial trick keeps robots dancing in sync

Broadcasting data allows machines to coordinate

By Rachel Ehrenberg

You don't have to watch *Dancing with the Stars* to know that keeping in sync is tough, and it's tougher still for a robot. But a new approach keeps robots in step, and even enables a robot that loses its footing to resynchronize with its peers.

One way to synchronize a group of robots is for each to communicate with one another about its position, but distance between the robots can lead to time delays. And when many robots are involved, the complexity of this communication network grows. To skirt such problems, researchers from MIT have taken inspiration from bacteria that synchronize their behavior not by checking in with each other, but by checking in with their environment.

Synchronizing robots this way might work well in rescue operations where robots are damaged and need to be replaced, says Paola Flocchini, a distributed computing expert at the University of Ottawa in Canada.

Many bacteria coordinate via a process called quorum sensing, which involves both releasing a steady stream of signaling molecules into the environment and then sensing the signaling molecules. When enough bacteria are around that the local concentration of these molecules soars, it's time for group action: Genes get turned on, molecular switches are flipped and the bacteria all change their behavior in sync.

Similarly, MIT's Jean-Jacques Slotine and Patrick Bechon coordinated the behavior of eight dancing humanoid robots by having the bots send information to — and get information from — an external computer server. The work appeared online May 14 at arXiv.org.

The robots go through cycles of prescribed actions, such as bobbing their heads, and send the server information about where they are in these cycles. The server then sends the average of this information back to all the robots. So a robot joining its dancing peers will check in with the server about what the other robots are doing. It can then calculate what the next movement is in the synchronized cycle and rejoin the group. Information about the music — in the test case, Michael Jackson's "Thriller" — is also embedded in the information sent back to the robots.

Incorporating math that describes the oscillating movements of body parts, such as arms and heads, is quite clever, says Mehran Mesbahi of the University of Washington in Seattle, whose research includes spacecraft navigation and control. It's much harder to incorporate information on position, angles and music, he says, than to have a simple command such as "March." ■

MIT NONLINEAR SYSTEMS LABORATORY, ALDEBARAN ROBOTICS

Sending information to and from an outside server keeps these robots in sync and even allows a robot that has fallen out of step to rejoin the group.

Animals on the

Fuzzy, bright-eyed and no bigger than a baked potato, the American pika is the kind of critter you could imagine starring in a blockbuster animated movie for kids. With its high-pitched squeaks, its lightning quickness and its habit of racing around all summer to harvest and sun-dry "hay piles" of grasses and wildflowers for its winter meals, the tiny rabbit relative is one comical ball of fluff. But what's happening to the pika is anything but amusing: Climate change has it in the hot seat.

Thick fur, heat-conserving roundish bodies and the use of snowpack as insulation help pikas survive in chilly alpine regions of the western United States and southwestern Canada. Their tolerance range is absurdly narrow, though. They can overheat to the point of death if exposed to too much summer heat. Extreme cold in the winter is just as deadly if they can't take refuge under the snow.

As alpine temperatures warm and snowpacks shrink, pikas in some places have hightailed it upslope to find more tolerable conditions. But in the arid, mountainous region known as the Great Basin, pikas have disappeared altogether from 40 percent of the locales where they were found in the first half of the 20th century. Apparently already at the upper limits of their ranges, they've run out of places to run to.

The pika's plight may be extreme, but the story line is not unusual. Worldwide — on land, in the sea and in rivers, streams and lakes — wildlife is responding to rising temperatures. The changes are sometimes to the animals' benefit, sometimes to their peril, say scientists who have pored over reams of recent studies and data from centuries of naturalists' observations.

Some animals are packing up and moving, generally heading toward the poles or up mountain slopes in search of more hospitable climes. Others are undergoing changes in physiology, behavior or body size — or they're shifting the timing of seasonal events such as breeding, migration and emergence from hibernation to coincide with earlier springs and later autumns. Just last year,

researchers reported seasonal shifts in animals ranging from snow geese in the Arctic to amphibians in a South Carolina wetland to penguins in Antarctica.

And though similar responses have been turning up in many sorts of animals, in many sorts of habitats, researchers are now finding that not all organisms are responding at the same rate or in the same direction. Long-standing associations between predators and prey, parasites and hosts, herbivores and food plants, flowers and pollinators are getting out of sync. Communities are breaking up and reassembling with new mixtures of members, and it's hard to predict the effects of such mash-ups, a team of environmental scientists concluded in a paper last year.

This shifting and reshuffling of the world's wildlife presents conservation challenges, to which scientists are now turning their attention. What good are nature preserves if changing climate forces safeguarded species to flee into unprotected areas? Or if protected populations perish because, already at the very top of a mountain or at one or the other of Earth's poles, they can go no farther? Or because, as one author wryly put it, "Los Angeles will be in the way" — meaning that suitable habitats into which animals might relocate have been turned into subdivisions and shopping malls, and escape routes to more distant habitat patches have been blocked.

mals move

A warming climate means shifting ranges and mixed-up relationships for a lot of species

By Nancy Ross-Flanigan

Prospecting for patterns

Coming up with a cohesive picture of how biological systems are reacting to climate change is a tricky task. Two research groups took up the challenge about a decade ago and published their initial, landmark studies — both still widely cited — in 2003 in the same issue of *Nature*.

"At that time there wasn't much out that was pulling things together at all," recalls Stanford University biologist Terry Root, who headed one of those groups. "I had organized a workshop in 1995 for looking at impacts on species of climate change, and three talks in that workshop had the same plot — different continents and different species, but all showing that species were doing things earlier. I thought, we need to sit back and figure out if this is really going on worldwide."

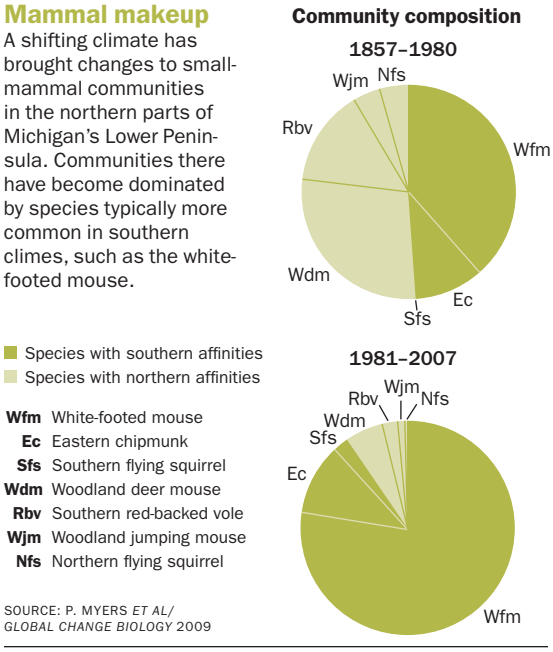
Root and coauthors synthesized information from 143 previously published studies and uncovered a consistent fingerprint — a temperature-related shift in range, seasonal events, behavior or other traits — in species "from molluscs to mammals and from grasses to trees." Of the species that showed changes, more than 80 percent were shifting in the directions you'd expect if the shifts were due to climate change.

In the other paper, biologist Camille Parmesan of the University of Texas

The American pika is second to only the polar bear as a symbol of a warming climate's effects on animals. As their habitats have changed, pikas have hightailed it upslope.

Mammal makeup

A shifting climate has brought changes to small-mammal communities in the northern parts of Michigan's Lower Peninsula. Communities there have become dominated by species typically more common in southern climes, such as the white-footed mouse.



SOURCE: P. MYERS *ET AL*/ *GLOBAL CHANGE BIOLOGY* 2009

at Austin and economist Gary Yohe of Wesleyan University in Middletown, Conn., performed various analyses on data from independent studies on more than 1,700 animal, plant and lichen species. Parmesan and Yohe also found biological trends that matched climate change predictions. Butterflies, birds and other organisms had shifted their ranges northward by an average of 6.1 kilometers per decade (or 6.1 meters per decade upward to higher altitudes). Amphibians and migratory birds, among others, were breeding earlier in the spring by an average of two days per decade (*SN: 3/8/03, p. 152*).

Since then, researchers around the world have been piling up more and more examples of particular animals or suites of species showing changes that fit the same patterns (as well as some that don't). On the range-shifting side of the story, more than half of 305 common North American birds are wintering farther north than they did in 1966, a National Audubon Society analysis showed in 2009 (*SN Online: 2/10/09*). The shifts, which average 56 kilometers and are as great as nearly 700 kilometers for individual species, coincide with warmer winter temperatures over the same period.

In Michigan, opossums, white-footed mice and other mammals once confined to the southern part of the state have rapidly expanded northward, displacing some of their counterparts in the process. A 2009 paper ruled out forest regeneration and land-use changes as possible explanations for the expansion; the authors concluded that warming, documented in the area over the same period, was the probable cause. Meanwhile, chipmunks and other small mammals in California's Yosemite National Park have moved to higher ground as temperatures in the park have increased in the last century, a 2008 study showed.

Such shifts can shake up communities, and the new assemblages that result may not get along as well as the old gang did. So concluded researchers who used climate and species-distribution models to project future bird communities in California. The upshot of their paper, published in 2009 in *PLoS ONE*: By 2070, more than half the state could be occupied by entirely new groupings of feathered fauna, with the potential for "dramatic community reshuffling and altered patterns of species interactions."

Even when interacting species move together, they may not link up in the same way in the new location. When warming nudged Britain's brown argus butterflies northward, their larvae were far less plagued by parasitoids in the new territory than they had been in the old home, researchers reported in *Ecological Entomology* in 2008. The parasitoids were in the new place, too, but apparently more interested in a different butterfly species.

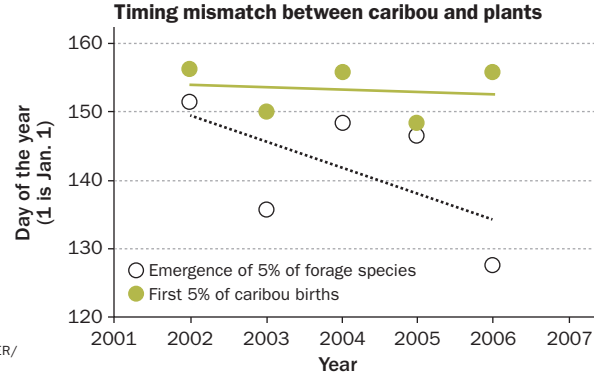
As for changes in seasonal activity, frogs are calling, birds are nesting, salmon are migrating, walleye are spawning, loggerhead turtles are laying eggs and bees and butterflies are appearing earlier in the spring. Plants too are responding by leafing out and flowering earlier (see Page 13).

Underscoring the individual reports, a 2010 study found that seasonal events in the United Kingdom have advanced for most of the 726 terrestrial, freshwater and marine plants and animals examined and that the rate of change has sped up in recent decades. What's more, change was speediest in organisms at the bottom of the food chain — plants and plant-eaters — and slower in predators, a situation that could result in empty bellies for the planet's top diners.

Mismatches can happen, too, when interacting species respond to different cues — say, one to day length and the other to temperature. That's what's happening with caribou in West Greenland, which synchronize their seasonal migration to calving grounds with day length. The food plants on which they depend respond to temperature, however, and as spring temperatures in the area have risen by more than 4 degrees Celsius, plants have started growing earlier. Caribou are now arriving after peak foraging time, fewer calves are being born and more calves are dying, a 2008 study found.

Out of sync

Caribou birthing dates have remained steady because the schedule is timed to day length. But the plants that caribou feed on respond to temperature, so they have been emerging earlier as temperatures in West Greenland have increased. Such mismatches could be a common effect of climate change.



SOURCE: E. POST AND M.C. FORCHHAMMER/ *PHIL. TRANS R. SOC. B* 2008

How the shake-ups will all shake out is hard to tell, concluded authors of a review published last year in the *International Journal of Biometeorology*. In their roundup of climate-driven mismatches between interacting species, environmental scientist Alison Donnelly of Trinity College Dublin and colleagues found examples of both winners and losers, as well as some partnerships that stayed in sync and some previously mismatched pairs brought into synchrony by rising temperatures. It's a complicated picture, and to get a handle on how individual species and whole ecosystems will respond to future climate change, scientists will need to delve deeply into relationships among species, the authors contend.

Root agrees: "What we need to be doing now is actually figuring out how the shifts are affecting biotic interactions so that we know what's going to happen as far as extinctions go."

Big picture projects

Teasing apart those interactions, while continuing to document overarching trends, will require heaps of data from long-term monitoring projects that span disciplines, environments, species and food chain levels, Donnelly and coauthors say. One such effort is the USA National Phenology Network (see Page 32). This consortium of researchers, citizen scientists and organizations collects and shares information on plant and animal phenology (the knowledge of when recurring life stages happen and how they relate to climate and change of season).

Changes in phenology are among the most sensitive indicators of global change and, fortuitously, some of the easiest to track. For centuries, people have been paying attention to the seasonal patterns of plants and animals, partly for enjoyment but also to know when to hunt and fish or be on the lookout for particular crop pests. Capitalizing on that interest, the Tucson-based network recruits volunteers to record phenological observations on 166 species of animals and 258 species of plants in an online Nature's Notebook.

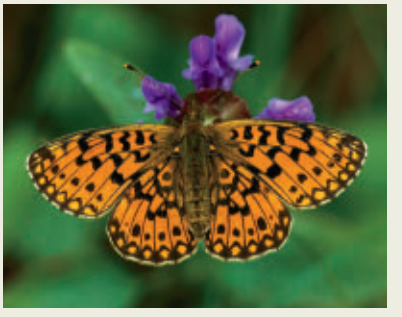
Climate responders

Over the last dozen years or so, scientists have linked a plethora of changes in the animal community to a warming climate.

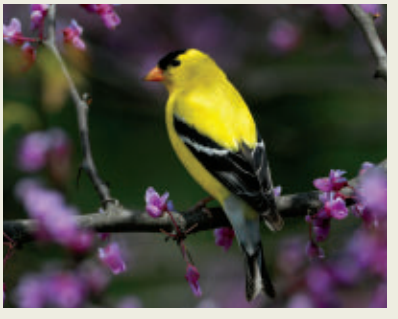
Marbled salamander
(Ambystoma opacum)
Fall breeding times have shifted for members of this species living in a wetland in South Carolina, with the start of breeding delayed by more than two weeks from 1981 to 2007.

Southern flying squirrel
(Glaucomys volans)
Flying squirrels in Michigan's Lower Peninsula have expanded their range northward in recent decades, while those in the Upper Peninsula have gone eastward. The squirrels are now found 225 kilometers northeast of their pre-1960s range limit.

Adélie penguins
(Pygoscelis adeliae)
Penguins living at four sites along the western Antarctic Peninsula advance the start of their nesting by almost two days per degree Celsius change in October temperatures.



Small pearl-bordered fritillary
(Clossiana selene)
Though the northern limit of the European range of this butterfly remained stable during recent decades, the southern extent of the range contracted over the same period — shrinking the total range.



American goldfinch
(Spinus tristis)
The midpoint of the range of this species' wintering grounds has moved more than 300 kilometers northward in the last four decades.

Black surfperch
(Embiotoca jacksoni)
A decline in abundance in this species in the Southern California Bight between the early 1980s and 1995 was linked to the drop in habitat productivity brought by warming waters.

CLOCKWISE FROM TOP LEFT: © LYNDA RICHARDSON/CORBIS; NICHOLAS JR/GETTY IMAGES; © THOMAS MARENT/MINDEN PICTURES/CORBIS; © LAURENCE F. TAPPER/AGE FOTOSTOCK; DOMINICK SPOLITINO/GETTY IMAGES; © JEFF VANUGA/CORBIS

"The beauty is that we have scientists and citizen volunteers all using the same protocols to collect the information," says Jake Weltzin, the network's executive director. This process creates a seamless dataset on a wide variety of organisms across the nation that researchers, conservation groups and others can use to piece together the big picture.

In addition to monitoring what's going on right now, the organization is tracking down and organizing records of what has happened in the past. "About 10 percent of the people in any audience I'm talking to have some kind of phenology records they've been keeping on anything from when maple syrup comes to when they applied insecticide on their grapes," Weltzin says. "We want to create a clearinghouse for these kinds of historical datasets."

Establishing cause

From the earliest studies through the current efforts, a major challenge has been verifying that observed changes in animal distribution, seasonal activities and so on are actually linked to climate change, and then disentangling the relative contributions of natural temperature fluctuations and human-caused temperature increases.

In their 2003 papers, both the Root group and Parmesan and Yohe relied on inference. The logic went like this: Their analyses revealed trends — across many species, ecosystems and geographic regions — that were in the direction you'd expect if climate change were driving the responses. Knowing that global warming had been clearly documented over the same period and that the Intergovernmental Panel on Climate Change had concluded that the warming was linked to the rise in greenhouse gases, the researchers felt justified in claiming that, as Parmesan later wrote in a review paper, "twentieth-century anthropogenic global warming has already affected Earth's biota."

Critics weren't convinced. Some argued that data showing temperature increases were collected in hotter urban areas, not where the animals exhibiting trends actually lived.

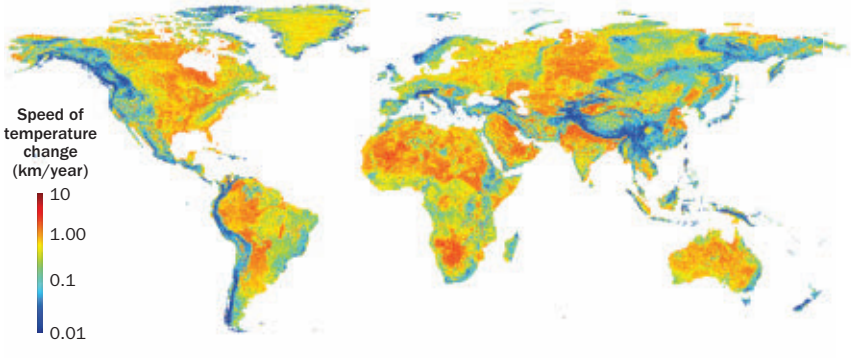
"I was getting fed up with the naysayers," Root says, "so in 2005 I looked at species change in relation to actual temperatures recorded at the particular study sites." The study that she and her coauthors published that year in the *Proceedings of the National Academy of Sciences* showed a strong link between local temperatures and the timing of biological events. The researchers then looked to see how the observed biological changes fit various climate scenarios generated from three different versions of global climate models: one based only on natural climate variability, one based only on human-caused climate change and one that factored in both natural and human-caused changes. The best fit was with the combined model; the worst was with natural climate variation alone.

"That was just a way of showing that yes, indeed, humans are a part of this," says Root, who endorses efforts to further clarify the relative contributions of natural and anthropogenic climate change, while conceding that it makes no difference to plants and animals what's causing the warming. "From a species perspective, it does not matter why the climate is changing, just that it is. From a human perspective, it does matter a lot, because knowing the reason can help us to stop our behavior that is driving the rapid changes."

Parmesan, however, thinks the pursuit amounts to unproductive hair-splitting. In a commentary published last year in *Nature Climate Change*, she and coauthors argued that the whole picture is too complex to ever say with certainty that a particular response in a given animal species is due to human-induced climate change. For one thing, animals respond to local climate, but human-caused climate change can be detected only on a larger spatial scale. What's more, other factors can interact with climate change, enhancing or masking its effects.

"Changes at the local level are going to be a complete mix of interactions among regional climate, habitat loss and local pollution sources," Parmesan says. Assessing and seeking to understand these interactions is a better use of time

Speed game A recent study analyzed how quickly climate change would move across the world during the 21st century, depicted below as the velocity one would have to move along Earth's surface to maintain a constant local temperature. Different ecosystems show varying average velocities (examples at bottom). SOURCE: S. LOARIE *ET AL*/*NATURE* 2009



0.08 km/yr
Tropical or subtropical coniferous forests

0.29 km/yr
Tundra

1.26 km/yr
Flooded grasslands and savannas

MAP: S.R. LOARIE *ET AL*./*NATURE* 2009; IMAGES, FROM LEFT: © JEAN-PAUL FERRERO/AUSCAPE/MINDEN PICTURES/CORBIS; PI-LENS/SHUTTERSTOCK; JACQUES JANGOUX/PHOTO RESEARCHERS, INC.

and resources than figuring out the specific role of greenhouse gases in driving biological change. Other researchers in the field also are calling for an integrated approach to future research that takes into account interacting environmental pressures, interconnected species and the varied sensitivities of different species to changing conditions. And because temperature isn't the only driver — some animals are showing behavioral and physiological changes in response to changing carbon dioxide levels or altered precipitation patterns — there are plenty more interactions to factor in.

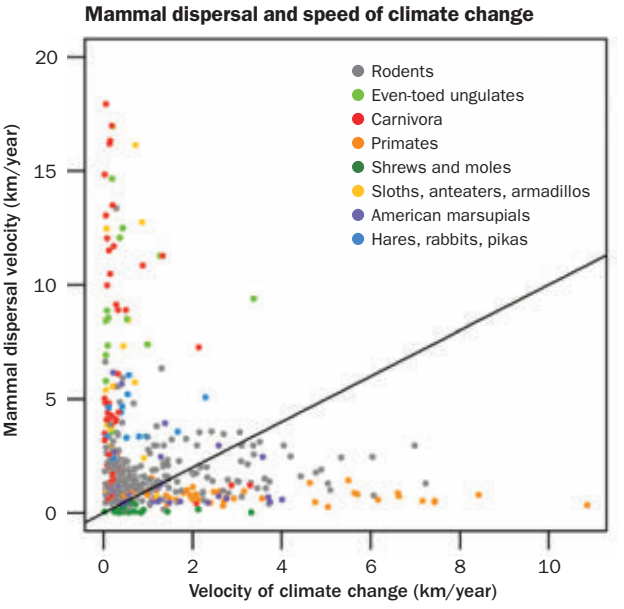
Another factor to consider is how quickly climate change is moving across the land, says Scott Loarie, a postdoctoral researcher who works with global ecologist Chris Field at Stanford. In 2009, Loarie, Field and colleagues found that, overall, species will need to move about two-fifths a kilometer per year to keep up with changing conditions, 10 to 100 times faster than they've ever had to move before to cope with changing climates. Mountain dwellers won't have to move as far as critters in flatter landscapes to find a new home — just 10 or so kilometers over the next century, compared with more than a hundred.

One recent study suggests ocean-dwelling animals may need to move as fast or faster than land species — and to advance the timing of breeding, spawning, migration and other seasonal life events even more. The work, from the marine biological impacts working group at the National Center for Ecological Analysis and Synthesis at the University of California, Santa Barbara, was published last year in *Science*.

The conclusions of Loarie and coauthors echo the 2003 findings of Parmesan and Yohe. But instead of documenting changes that have already occurred, Loarie's group developed an index that can be used to predict future range shifts. Applying their predictions to nature preserves worldwide, the researchers arrived at the dire conclusion that traveling temperatures will force wildlife out of all but 8 percent of those reserves within a century.

Keeping pace

About 9 percent of Western Hemisphere mammal species may not be able to move to new habitats fast enough to keep up with the pace at which climate change is altering local conditions (velocity of climate change is a measure of the pace required to maintain similar climatic conditions). Mammal species that, on average, won't move fast enough fall below the diagonal black line in the graph at right.



SOURCE: C.A. SCHLOSS *ET AL*/ *PNAS* 2012

Looking at the problem from a slightly different angle — how far animals actually are able to travel to establish new homes and how inclined they are to do so — researchers at the University of Washington in Seattle also came up with grim figures. This year in the *Proceedings of the National Academy of Sciences* (*SN Online: 5/14/12*), Carrie Schloss and colleagues found that about 9 percent of mammal species in the Western Hemisphere won't be able to move fast enough to keep pace with climate change. In some areas, more than half the mammal species will be unable to keep up.

The Loarie and Schloss studies don't just spin out gloomy scenarios, though. They also point to conservation strategies, such as designing reserves that include a range of landscapes — and associated climate regimes — and creating linked networks of protected areas.

Given the complex, interconnected pressures on animals these days, the varied ways species are responding and the projections that temperature may rise another 1.8 to 4 degrees by the end of the 21st century, it's time to completely rethink conservation aims and approaches, says paleoecologist Anthony Barnosky. People have been accustomed to setting aside reserves and expecting them to simultaneously protect the natural landscape, the species that live there and the associated "ecosystem services" — ecological interactions that provide humans with food, clean water, recreational opportunities and the like. But now, with plants and animals moving around, old associations breaking up and new ones forming, it may no longer be possible to protect all three facets of nature at once.

"You have to decide, am I interested in a species? Am I interested in a landscape? Or am I interested in a feeling of wilderness?" says Barnosky, of the University of California, Berkeley. Saving species may mean actively intervening and helping animals move to areas they can't reach on their own. Protecting ecosystem services may — or may not — depend on keeping specific groups of species together. That's still an open question. And preserving wilderness, nature free from human meddling, will require "realizing that the species that live there today are probably going to be very different from the species that live there tomorrow." ■

Explore more

■ Anthony Barnosky. *Heatstroke: Nature in an Age of Global Warming*. Island Press, 2009.

Nancy Ross-Flanigan is a freelance writer based in Newaygo, Mich.

HURT BLOCKER

The next big pain drug may soothe sensory firestorms without side effects

By Rachel Ehrenberg

Among a small number of related families from northern Pakistan, some individuals never feel pain in any part of their bodies. Scientists studying six such children found that by the age of 4, they all had injuries to the lips or tongue from repeatedly biting themselves. Bruises, cuts and broken bones were common, though fractures were diagnosed only long after the fact, when weird, painless limping or the inability to use a limb called attention to the injury. Tests showed that the pain-free children perceived sensations of warm and cold, tickling and pressure. They could feel the prick of a needle, but it didn't hurt. Two had been scalded — painlessly — by hot liquids. And one boy who performed street theater by putting knives through his arms and walking on hot coals died after jumping off a roof on his 14th birthday.

Besides their inability to feel pain, the Pakistani individuals studied by the scientists had something else in common: mutations in a gene called *SCN9A*. That gene encodes the instructions for a protein that forms a passageway for letting sodium ions into nerve cells. Known as $Na_v1.7$, this particular ion channel sits on pain-sensing nerves; when a nerve is stimulated enough to warrant sending a signal to the brain, a flood of sodium ions rush into the cell.

Among the pain-free Pakistanis,

MICHAEL MORGENSTERN

Flavors of pain

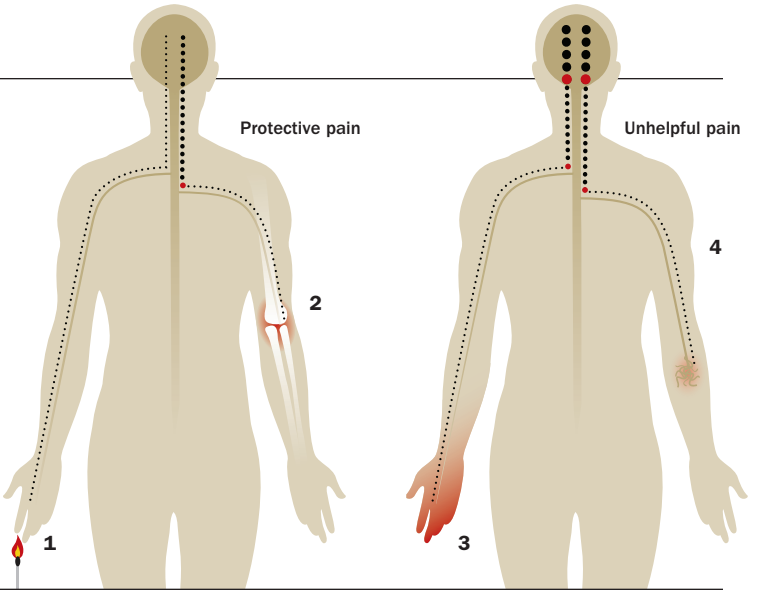
Pain is generally protective, prompting you to pull your hand off a hot stove or sit tight after an injury. But not all pain is alike, and it's not all helpful.

1. Nociceptive This type of hurt is a response to an intense stimulation of the nervous system, such as a stubbed toe or burnt finger.

2. Inflammatory The immune system can prompt this pain, which helps prevent long-term damage. Caused by fractures and infection, among other cellular-level assaults, this pain gets ramped up at the spinal cord.

3. Dysfunctional Genetic abnormalities that alter the way nerves sense stimuli — and the amplification of stimuli in the spinal cord and brain — can turn a gentle touch or no stimulus at all into a painful experience.

4. Neuropathic Damage that injures nerve fibers or causes lesions elsewhere in the central nervous system can cause long-lasting pain.



E. FELICIANO

various mutations in *SCN9A* altered the blueprints for $Na_v1.7$ in different ways, but with the same result: The channel didn't work. Muted nerve cells could no longer alert the brain when the body encountered something painful.

In other people, though, changes in the same gene make the channel work too well. Affected nerve cells distort or exaggerate their response, crying wolf when they encounter nonpainful stimuli or even when there is no stimulus at all. In January scientists reported seven $Na_v1.7$-related mutations in some people with unexplained cases of small fiber neuropathy, a condition that typically entails burning pain in the feet with intermittent stabbing, aches and sensations of electric shocks or pins and needles.

Small fiber neuropathy and congenital indifference to pain (the official name for the Pakistanis' pain-free condition) are just two of a handful of human pain disorders that have in the last decade been linked to malfunctioning $Na_v1.7$. Though some of these conditions are relatively rare, a growing body of research suggests that $Na_v1.7$ might play a part in more common persistent pain that follows nerve damage. Such pain can result from a bad burn or traumatic wound, or even accompany diseases such as diabetes.

As more new studies pile up, $Na_v1.7$ is beginning to look like a nerve channel of pharmaceutical company dreams.

"Potentially, these channels are just the most amazing drug target," says Geoff Woods of the Cambridge Institute for Medical Research in England, who led the study of the pain-free Pakistani children.

Channel Nº 1.7

Part of the excitement over $Na_v1.7$ stems from the fact that the channel may offer a solution to an ongoing problem in designing pain drugs: To avoid unwanted side effects, medications should act only on particular targets in particular places. Today's pain drugs aren't so choosy.

For example, lidocaine, an anesthetic that can be applied topically or injected, targets an entire class of sodium channels. It doesn't discriminate between channels on nerves related to pain and channels on other nerves; that's why affected areas feel totally numb. (Because it blocks sodium channels in the heart, the drug is sometimes used to treat irregular heart rhythms.)

Aspirin, ibuprofen and their kin inactivate enzymes that promote inflammation. But these enzymes also help protect the stomach from acid, assist in kidney function and help blood clot, so the drugs can increase the risk of ulcers, kidney failure and certain cardiovascular troubles. The chronic pain drug pregabalin, which is prescribed under the brand name Lyrica for some types of pain and seizures, hits widely distributed calcium ion channels. Because of the effects on channels in the brain, the drug can cause dizziness, drowsiness and other problems.

Then there are opiates, including Vicodin, OxyContin and morphine. These work on cellular machinery in the digestive tract, spinal cord and brain, so they can cause nausea, constipation, dizziness and breathing problems, as well as being highly addictive.

But $Na_v1.7$ is found predominantly in peripheral nerves at work in the outer territories of skin and muscle. So drugs that target this channel shouldn't make people groggy, put them at risk for heart problems or meddle with other organs such as the liver or kidneys. The fact that the pain-free Pakistani children were otherwise healthy suggests that a $Na_v1.7$ blocker wouldn't interfere with other body functions. (The only secondary effect of knocking out $Na_v1.7$ appears to be a reduced or lost sense of smell.)

Drugs aimed at $Na_v1.7$ might provide relief, with few side effects, to people with the kind of pain that persists when peripheral nerves malfunction. Such pain is like an alarm system gone haywire.

Typically pain is protective; it alerts you to impending or actual damage. Nociceptive pain (from the Latin *nocere*: to hurt or injure) delivers a red alert when you touch something dangerously sharp or hot. Nerve cells that sense this type of pain have a pretty high threshold, but once activated, the response is instantaneous: Your withdrawal reflex kicks in and you pull your hand away. Inflammatory pain, stimulated by immune system cells, occurs in response to injury. This pain warns you

not to move a broken arm, giving the bone time to heal.

But when physical injury, metabolic disorders such as diabetes, autoimmune diseases or viral infections assault nerve cells, pain is no longer protective. Nerves can become trigger-happy, set off by something as mild as the touch of bedsheets. An estimated 20 million people in the United States experience this kind of pathological pain in their extremities.

"There are a lot of people suffering, and it is really terrible for patients," says Catharina Faber of Maastricht University Medical Center in the Netherlands.

When examining a patient with such pain, Faber and her colleagues first look for an underlying condition that might have attacked the patient's nerves. In many cases, there's no obvious cause.

Research now suggests that genetic changes that alter $Na_v1.7$ may be a culprit. The seven *SCN9A* mutations linked to small fiber neuropathy in a study earlier this year appeared to explain the peripheral pain of nearly 30 percent of study participants. This study — reported by Faber, Maastricht colleague Ingemar Merkies and other collaborators in the *Annals of Neurology* — and other recent studies suggest that much of how pain is experienced is inherited. Many scientists now believe that genetic changes altering $Na_v1.7$, as well as other channels, may be behind a lot of chronic, pathological and mysterious pain.

Disorderly conduct

Stephen Waxman, who directs the Yale Center for Neuroscience and Regeneration Research and is a biomedical researcher with the U.S. Veterans Affairs health care system, has been investigating $Na_v1.7$ and its defects for more than a decade. Working with Faber, Merkies and others from around the world, researchers in Waxman's lab have identified more than two dozen mutations in *SCN9A*. One, reported in *Brain* in February, not only causes burning pain in the extremities, but may also influence development of the hands and feet. The many months of cell studies required to fully understand how each mutation influences $Na_v1.7$'s construction and operation have been carried out for about half.

The first definitive link between mutations in *SCN9A* and a human pain condition came in 2004. Researchers led by Yong Yang of Peking University First Hospital in Beijing reported two mutations in a family with several members suffering from primary erythromelalgia, a condition wherein $Na_v1.7$ channels open too readily and the body's extremities become red, swollen and burn with pain.

Then in 2006, an international team linked mutations that alter $Na_v1.7$ to paroxysmal extreme pain disorder. Formerly known as familial rectal pain, this lifelong condition is characterized by attacks of excruciating pain in various parts of the body, including the rectum, genitalia, eyes, jaw and limbs (the name was changed in part because the pain is not confined to the rectum). That same year, the team led by Woods reported the mutations causing an inability to feel pain in the families from northern Pakistan; additional mutations with the same effect have since been discovered worldwide.

These genetic studies cemented $Na_v1.7$'s prominent role in human pain perception. They also offered an unusual treat: Rarely do geneticists find a tidy and direct link connecting changes in a single gene with what scientists call a loss of function and its counterpart, a gain of function. Often the picture is much more complicated, with many genes contributing to a trait or disease.

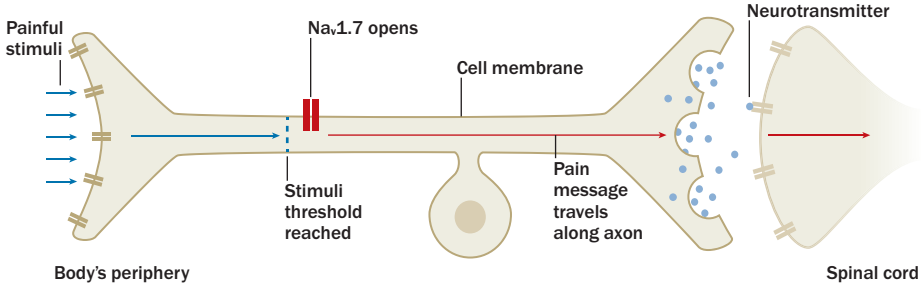
Yet *SCN9A* offered a textbook example: A single mutation in a single gene could cause a person to lose the ability to sense pain, while another mutation in that same gene could amp up that ability, making people feel pain even when they should not.

"The genetic demonstration was very clear. It was so clean. It's usually not that clean," says Simon Halegoua, director of the Center for Nervous System Disorders at Stony Brook University in New York. "That's when multiple drug companies jumped on it."

Halegoua saw $Na_v1.7$'s potential earlier. In 1997, he and colleagues published research describing a sodium channel found predominantly in the peripheral nervous system. Since it was the first such sodium channel, the researchers called it peripheral nerve type 1. Later, it became known as $Na_v1.7$ (Na for sodium and v for voltage-gated channel). Earlier studies in rats and human cells had hinted that some sodium channels favored certain body regions over others. Some did their stuff primarily in heart muscle, for example, and others acted mainly in the brain. But this was the first description of a sodium channel used mostly by peripheral nerves, at the front line of the body's interactions with the world.

"That was the breakthrough," says Halegoua. "It opened the door to an approach which would target those peripheral pain-sensing neurons specifically. It was a paradigm shift in the way of thinking about how to target pain. Instead of targeting it at the brain like opiates do, you would target it at the source — the first nerve that gets excited."

Cellular close-up An important gateway for sodium ions, called $Na_v1.7$, sits on nerve cells that stretch from the body's periphery all the way to the spinal cord. With enough stimuli at one end, the $Na_v1.7$ channel opens, passing along a message of pain to the spinal cord and brain.



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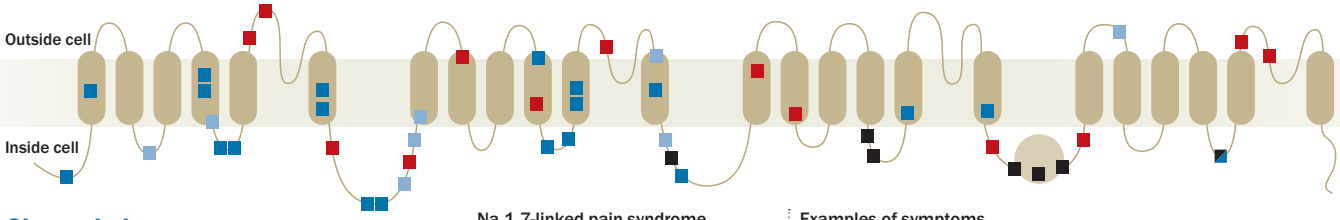

Channel changes Mutations in a gene called *SCN9A* can cause a number of pain disorders (right). This gene carries the instructions for an elaborate protein called $Na_v1.7$ (above) that lets sodium ions pass into a nerve cell. Boxes show locations where *SCN9A* mutations linked to different disorders alter the protein.

$Na_v1.7$-linked pain syndrome	Examples of symptoms
Small fiber neuropathy	Hypersensitivity to stimuli; red, painful extremities
Inherited erythromelalgia	Extremities become red, painful and swollen
Paroxysmal extreme pain disorder	Stabbing pain in the rectum, genitalia, eyes, jaw and limbs
Congenital indifference to pain	An absence of the sensation of pain

SOURCES: S. DIB-HAJJ *ET AL*/*TRENDS IN NEUROSCIENCES* 2007 AND I. MERKIES/MAASTRICHT UNIV. MEDICAL CENTER

Pain, pain, go away

The efforts of nearly two decades of research on $Na_v1.7$ are now bearing fruit. London-based Convergence Pharmaceuticals has developed a compound that blocks the channel only when nerves are firing like crazy. Normal pain thresholds, such as those experienced when touching a hot stove, aren't altered by the $Na_v1.7$ blocker, says Simon Tate, Convergence's chief scientific officer. The company's compound is now in Phase II clinical testing — the stage that looks at dosage and effectiveness — for a painful condition of the lower back and limbs called lumbosacral radiculopathy. Convergence has also started a Phase II trial testing the same $Na_v1.7$ blocker as a treatment for trigeminal neuralgia, a chronic pain condition that entails recurring brief episodes of intense, stabbing facial pain.

In January the Canadian company Xenon Pharmaceuticals reported success with an $Na_v1.7$ blocker for treating erythromelalgia, often referred to as "man on fire syndrome." And Pfizer and its subsidiary Icagen are working with Waxman and Yale colleague Sulayman Dib-Hajj to investigate a blocker for treating the same disorder.

Some conditions under investigation — lumbosacral radiculopathy and trigeminal neuralgia, for example — aren't caused by inherited mutations, but appear to result from nerve damage. If an $Na_v1.7$ blocker works in such cases, the target may prove useful for treating long-term debilitating pain more broadly. Good candidates may include the 60 to 70 percent of people with diabetes who have nervous system damage that can cause daily pain. People with traumatic injuries for which the healing time is long, such as a severe burn, may also benefit. Studies by Waxman and colleagues have found that mice without working $Na_v1.7$ channels don't develop the hypersensitivity to heat that typically follows a burn injury.

Beyond offering new tricks for treating pain when it strikes, studying the channel may also help doctors understand their patients' personal pain profiles. Recent research led by Woods found that some versions of *SCN9A* in people without known pain disorders can confer increased sensitivity to pain. Such studies may help explain why one solider who has been shot through the arm experiences chronic post-trauma pain, while another soldier with the same wound might not. Or why some amputees have phantom limb pain and others don't, says Waxman.

"It's very exciting to us," he says. "If you go into a room full of people who all look normal, 30 percent may have a lower threshold for pain and an increased likelihood of developing pain after nerve injury."

As scientists continue to investigate the nuances of $Na_v1.7$, some are turning to its channel brethren as well. $Na_v1.8$ and $Na_v1.9$, also sodium channels, are less understood than $Na_v1.7$. But scientists do know that these channels also play a role in generating pain, and therefore may be promising targets too, says Michael Costigan, a specialist in the genetics of chronic pain at Boston Children's Hospital. Changes in the behavior of $Na_v1.8$ have been implicated in inflammatory pain, for instance.

Other pain-related channels being studied include transient receptor potential, or TRP, channels, which play an important role in detecting nociceptive pain, warm and cold, and the fire of wasabi and chili peppers. Some TRP blockers are under investigation for treating migraines, postsurgical pain and pain from nerve damage. And Costigan and colleagues recently reported that people with a particular version of a potassium channel gene are more likely to develop chronic pain after an injury.

The sheer number of ion channels now known to play some role in pain and the overlap of those roles highlight how important pain is for safety and survival — a fact not lost on the researchers who are trying to beat it.

There's potential danger that comes with the promise of a superior pain drug. Total pain blockers with few side effects could be abused by athletes or others who want to ignore an injury, allowing them to do even more damage. Such drugs might also quiet warnings of a new and serious condition, such as an intestinal obstruction or a stroke. As with the Pakistani children, living pain-free might even result in severe trauma and early death.

"If we have a really effective block, it could be dangerous," Halegoua says. "We need pain." ■

Explore more

■ C.J. Woolf. "What is this thing called pain?" *The Journal of Clinical Investigation*. November 2010.

E. FELICIANO

A MIND F

Alan Turing foresaw machines' potential to mimic brains

By Tom Siegfried

Arguably, and it would be a tough argument to win if you took the other side, computers have had a greater impact on civilization than any other machine since the wheel. Sure, there was the steam engine, the automobile and the airplane, the printing press and the mechanical clock. Radios and televisions also made their share of societal waves. But look around. Computers do everything TVs and radios ever did. And computers tell time, control cars and planes, and have rendered printing presses pretty darn near obsolete. Computers have invaded every realm of life, from work to entertainment to medicine to education: Reading, writing and arithmetic are now all computer-centric activities. Every nook and cranny of human culture is controlled, colored or monitored by the digital computer. Even though, merely 100 years ago, no such machine existed. In 1912, the word *computer* referred to people (typically women) using pencils and paper or adding machines.

Alan Turing, often considered the father of computer science, was born a century ago, in June of 1912.

Coincidentally, that was the year that Alan Turing was born. If you don't like the way computers have taken over the world, you could blame him.

No one did more to build the foundation of computer science than Turing. In a paper published in 1936, he described the principle behind all of today's computing devices, sketching out the theoretical blueprint for a machine able to implement instructions for making any calculation.

Turing didn't invent the idea of a computer, of course. Charles Babbage had grand plans for a computing machine a century earlier (and even he had precursors). George Boole, not long after Babbage, developed the underlying binary mathematics (originally conceived much earlier by Gottfried Leibniz) that modern digital computers adopted. But it was Turing who combined ideas from abstract mathematical theory and concrete mechanical computation to describe precisely how, in principle, machines could emulate the human brain's capacity for solving mathematical problems.

"Turing gave a brilliant demonstration that everything that can be reasonably said to be computed by a human computer using a fixed procedure can be computed by ... a machine," computer scientist Paul Vitányi writes in a recent paper (online at arxiv.org/abs/1201.1223).

Tragically, though, Turing didn't live to see the computer takeover. He died a victim of prejudice and intolerance. His work lived on, though, and his name remains fixed both to the idealized machine he devised and to a practical test for machine intelligence, a test that foreshadowed powers that today's computers have begun to attain.

Turing's machine

Born in London on June 23, 1912, Turing grew up in an era when mathematics was in turmoil. Topics like the nature of infinity, set theory and the logic of axiomatic systems had recently commandeered the attention of — and confused — both practitioners and philosophers interested in the foundations of mathematics. Constructing an airtight logical basis for proving all mathematical truths had been established as the ultimate goal of mathematical inquiry.

But in 1931, Austrian logician Kurt Gödel dashed that hope, proving that some true statements could not be proved (within any mathematical system sufficiently complex to be good for anything). In other words, no system built on axioms could be both complete and internally consistent — you couldn't prove all true statements about the system by deductions from its axioms.

A second deep question remained, though. Even if not all

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true statements can be proved, is there always a way to decide whether a given mathematical statement is provable or not?

Turing showed the answer to be "no." He wasn't the first to figure that out; as he was finishing his paper, the American logician Alonzo Church at Princeton published his own proof of such "undecidability." Turing's triumph was not in the priority of his claim, but rather in the creative way his proof was constructed. He proved the "no" answer by inventing his computer.

He didn't actually build that computer (at first, anyway), nor did he seek a patent. He conceived a computational machine in his imagination — and outlined the essential principles by which it would work — to explore the limits of mathematics.

Turing's machine was deceptive in its conceptual simplicity. Its basic design consisted of three parts: a limitless length of tape, marked off by squares on which symbols could be written; a read-write "head" that could inscribe symbols on the tape and decipher them; and a rule book to tell the machine what to do depending on what symbol the head saw on the tape.

These rules would tell the head both what to do in response to a given symbol and then which rules to use next. Suppose, for instance, the head detects a 1 on the tape. A possible rule might be to move one square to the left and write a 1; or move one square to the right and write a 0; or stay on that square, erase the 1 and leave the square blank. By following well-thought-out rules, such a mechanism could compute any number that could be computed (and write it as a string of 0s and 1s).

One of the prime consequences of Turing's analysis was his conclusion that some numbers could not be computed. He adopted Gödel's device of assigning a number to every possible mathematical statement and then showed that this inability to compute all numbers implied that the provability of some statements could not be decided. (And Turing showed that his proof of undecidability was also equivalent to Church's more complicated proof.) Turing's result was immediately recognized as exceptional by his professor at the University of Cambridge, who advised Turing to go to Princeton for graduate school and work with Church.

Turing's imaginary computer (christened by Church the "Turing machine") offered additional lessons for future computer scientists. Depending on the type of calculation you wanted to perform, you could choose from Turing machines with different sets of instructions. But, as Turing showed, you have no need for a roomful of machines. A portion of one computer's tape could contain the rules describing the operations needed for carrying out any particular computation. In other words, you can just give that machine a rule book (today, you'd call it a program) that tells it what to do. Such a "universal Turing machine" could then be used to solve any problem that could be solved.

During his time at Princeton, Turing discussed these ideas with the mathematician John von Neumann, who later articulated similar principles in describing the stored program general purpose computer, the model for digital computers ever since. Today's computers, whether Macs or PCs or teraflop supercomputers, are all Turing machines.

"Von Neumann realized that Turing had achieved the goal of defining the notion of universal computing machine, and went on to think about practical implementations of this theoretical computer," writes Miguel Angel Martín-Delgado of Universidad Complutense in Madrid in a recent paper (arxiv.org/abs/1110.0271).

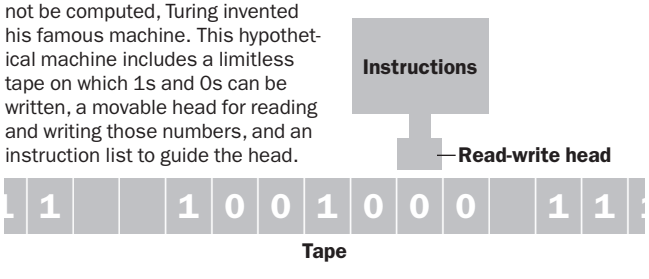
Computing thoughts

Turing's thoughts about his machine went well beyond the practicality of mixing math and mechanics. He was also entranced by the prospect of machines with minds.

To specify which rule or set of rules to follow, Turing assigned his machine a "state of mind." More technically, he called that state a "configuration." After each operation, the

Computer construct

To show that some numbers could not be computed, Turing invented his famous machine. This hypothetical machine includes a limitless tape on which 1s and 0s can be written, a movable head for reading and writing those numbers, and an instruction list to guide the head.



B. RAKOUSKAS

rules specified the machine's configuration; the configuration in turn determined what rule the machine should implement next. For instance, in configuration "B," if the head is positioned over a blank square, the instruction might be to write a 0 on the square, move one position to the right and then assume configuration C. In configuration C, a head positioned over a blank square might be instructed to write a 1, move one square to the right and then assume configuration A.

When Turing referred to the machine's configuration as its "state of mind," he really did consider it analogous to the state of mind of a human computer, using a notepad, pencil and rule book rather than tape, head and program. Turing's imaginary machine demonstrated that the computing abilities of the person and the mechanical computer were identical. "What he had done," wrote his biographer, Andrew Hodges, "was to combine ... a naïve mechanistic picture of the mind with the precise logic of pure mathematics."

Turing believed that people were machines — that the brain's magic was nothing more than physics and chemistry "computing" thoughts and behaviors. Those views emerged explicitly years later, when he devised the now-famous test of artificial intelligence that goes by his name. To analyze whether machines can think, Turing argued, the question must be posed in a way that enables an empirical test. As commonly described, the Turing test involves a human posing questions to an unseen respondent, either another human or a computer programmed to pretend to be human. If the computer succeeds in deceiving the interrogator, then — by Turing's criteria — it qualifies as intelligent.

Turing believed that people were machines — that the brain's magic was nothing more than physics and chemistry "computing" thoughts and behaviors.

Actually, Turing's proposal was a bit more elaborate. First, the interrogator was to pose questions to two unseen humans — one man, one woman — and attempt to determine which one was which. After several trials, either the man or the woman was to be replaced by a computer, and the game repeated, this time the interrogator attempting to tell which respondent was human. If the interrogator succeeded no more often in this task than when the respondents were both human, then the machine passed the thinking test.

Since Turing's paper appeared, in 1950, multiple objections to his test have been raised (some of which Turing anticipated and responded to in the paper). But the test nevertheless inspired generations of computer scientists to make their machines smart enough to defeat chess grandmasters and embarrass humans on *Jeopardy!* Today you can talk to your smartphone and get responses sufficiently humanlike to see that Turing was on to something. He even predicted a scenario similar to something you might see today on a TV commercial. "One day ladies will take their computers for walks in the park and tell each other 'My little computer said such a funny thing this morning!' " he liked to say.

Turing seeded a future in which machines and people interact at a level that is often undeniably personal. But he was not around to participate in the realization of his imaginations. Four years after that paper on artificial intelligence appeared, he was dead.

A surviving vision

During World War II, Turing had been the key scientist in the British government's code-breaking team. His work on cracking the German Enigma code was, of course, a secret at the time, but later was widely recognized as instrumental in the Allies' defeat of Germany. After the war, Turing returned to computer science, eventually developing software for a sophisticated (at the time) programmable computer at the University of Manchester.

While in Manchester, he composed his paper on the artificial intelligence test. Later there he encountered the lack of intelligence in the British criminal code. During a police investigation of a break-in at Turing's home, he acknowledged that he knew the culprit's accomplice from a homosexual encounter. And so Turing became the criminal, prosecuted for "gross indecency" under a law banning homosexual acts. Upon his conviction, Turing chose the penalty of chemical castration by hormone injection rather than serving a term in prison. His security clearance was revoked.

Two years later, Turing's housecleaner found him dead in bed, a partly eaten apple at his bedside. It was officially ruled a suicide by cyanide. At the age of 41, the man who played the starring role in saving Western democracy from Hitler became the victim of a more disguised form of evil.

In his tragically truncated life, Turing peered more deeply into reality than most thinkers who had come before him. He saw the profound link between the symbolisms of mathematical abstraction and the concrete physical mechanisms of computations. He saw further how computational mechanisms could mimic the thought and intelligence previously associated only with biology. From his insights sprang an industry that invaded all other industries, and an outlook that today pervades all of society. Science itself is infused with Turing's information-processing intuitions; computer science is not merely a branch of the scientific enterprise — it's at the heart of the enterprise. Modern science reflects Turing's vision. "He was," wrote Hodges, "the Galileo of a new science." ■

Explore more

■ A. Hodges. *Alan Turing: The Enigma, The Centenary Edition*. Princeton University Press, 2012.

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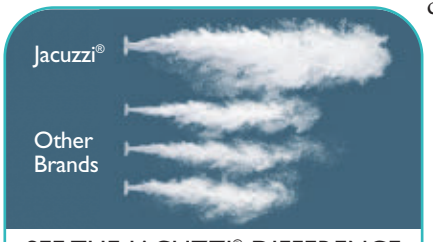

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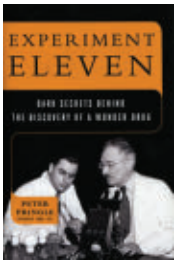
Experiment Eleven

Peter Pringle

In 1943, Rutgers graduate student Albert Schatz isolated two strains of bacteria that produced an unknown antibiotic. As World War II raged in Europe, tuberculosis and other diseases tore through refugee camps. New antibiotics were sorely needed, as Schatz, a former Army lab technician, knew well. He noted the new find under the heading "Exp. 11" in his lab notebook and shared his notes with his adviser, soil microbiologist Selman Waksman.

The antibiotic, streptomycin, became the first effective treatment for tuberculosis. As word of streptomycin's success made its way into the papers, though, a strange thing happened. Schatz had made the discovery and performed the initial tests against TB, but Waksman alone received the credit. This wasn't accidental. Waksman, Pringle writes, had launched "a furious and sometimes wacky campaign" to keep Schatz out of the limelight. Though others have previously set the record straight about Schatz's role, Pringle gives Schatz his due in this comprehensive account of the story, pieced together from personal interviews and Waksman's papers.

Tensions about the discovery grew until 1950, when Schatz leveled a lawsuit against his one-time adviser. The case ended in a settlement that gave Schatz the legal title of codiscoverer and a share of royalties. But the 1952 Nobel Prize in Physiology or Medicine went to Waksman for the discovery of streptomycin; Schatz, the committee ruled, was merely "an assistant of inferior rank."



Pringle, a journalist, dedicates the book to researchers "who did the hard work, and never reaped the glory." He opens up questions about ethics in research, and about who really deserves recognition in the team effort of scientific discovery. —*Allison Bohac*

Walker & Co., 2012, 254 p., $26

Mr. Hornaday's War

Stefan Bechtel

William Temple Hornaday may have been a small man, but there was nothing diminutive about the naturalist's ego, bravery, energy or ambition. Born a few years before the U.S. Civil War, the tenacious naturalist accomplished so much in his 82 years that Bechtel's biography of him reads like larger-than-life fiction. Yet few will recognize Hornaday's name.

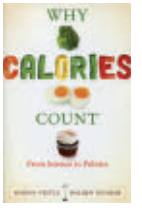
He was almost solely responsible for bringing the American buffalo back from the brink of extinction and played a crucial role in saving Alaskan fur seals from a similar fate.

Beginning his career as a taxidermist, Hornaday would become a father of the American wildlife conservation movement. He not only developed plans for the National Zoo in Washington, D.C., but also collected its initial specimens and cared for them on the National Mall. Shortly afterward, he was ousted as zoo director — only to be recruited to design and run the Bronx Zoo.

Hornaday proved especially indefatigable in a nearly six-decade-long war against the plunder of wildlife, instigating legal protections for many animals and pioneering captive breeding for endangered species. The irony: He was a crack shot who throughout his 20s traveled the world killing and collecting animals — albeit in the name of science.

Bechtel doesn't present Hornaday as a saint. But a full accounting of this complex man probably deserves a little deeper probing into events that seem to dirty Hornaday's otherwise fairly white hat — like his inability to understand the hullabaloo over his short-term display of a homeless pygmy in his zoo's monkey house. —*Janet Raloff*

Beacon Press, 2012, 288 p., $27.95



Why Calories Count

Marion Nestle and Malden Nesheim

Two food experts battle misconceptions about the fundamental unit of food science and give advice for a healthy diet. *Univ. of California, 2012, 303 p., $29.95*

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Till Roenneberg

Depression, weight gain and sickness are just a few of the health risks when internal biological clocks fall out of sync with daily life, a chronobiologist warns. *Harvard Univ., 2012, 272 p., $26.95*

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Statins oversold

The article that extols statins' purported benefits for conditions ranging from infection to cancer ("Another side to statins," *SN: 5/5/12, p. 30*) does not reflect the balance of evidence. Both favorable and adverse mechanisms apply. We regularly hear from patients who have suffered serious adverse effects, for whom data had not supported expectation of net benefit with statin use but who were prescribed statins by exuberant physicians influenced by the promise of benefits extolled in worshipful, imbalanced (if well-intentioned) articles like this.

Beatrice A. Golomb, Athena Hathaway Meskimen and Hindu Rao, San Diego, Calif.

Primed for priming

Concerning the recent article "The hot and cold of priming" (*SN: 5/19/12, p. 26*), I want to give a shout-out to Joseph Cesario of Michigan State University, who says that priming critics are threatened by evidence that complex thinking doesn't require conscious thought. This parallels a maxim in the animal behavior course that I teach. Namely, just as we need to investigate consciousness as a factor in other animals' behavior, we need to recognize that much of our human behavior is subconsciously driven. We are not always consciously "rational" in our actions, but often are consciously rationalizing behavior to ourselves and others that was primed and enacted subconsciously.

J. Roger Eagan, Queensbury, N.Y.

Correction

A Science Stats graphic showing the relationship between body piercings and alcohol consumption (SN: 5/19/12, p. 4) *incorrectly labeled the units of alcohol content as grams per liter of exhaled breath. The correct units are milligrams per liter of exhaled breath.*

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The Science Life

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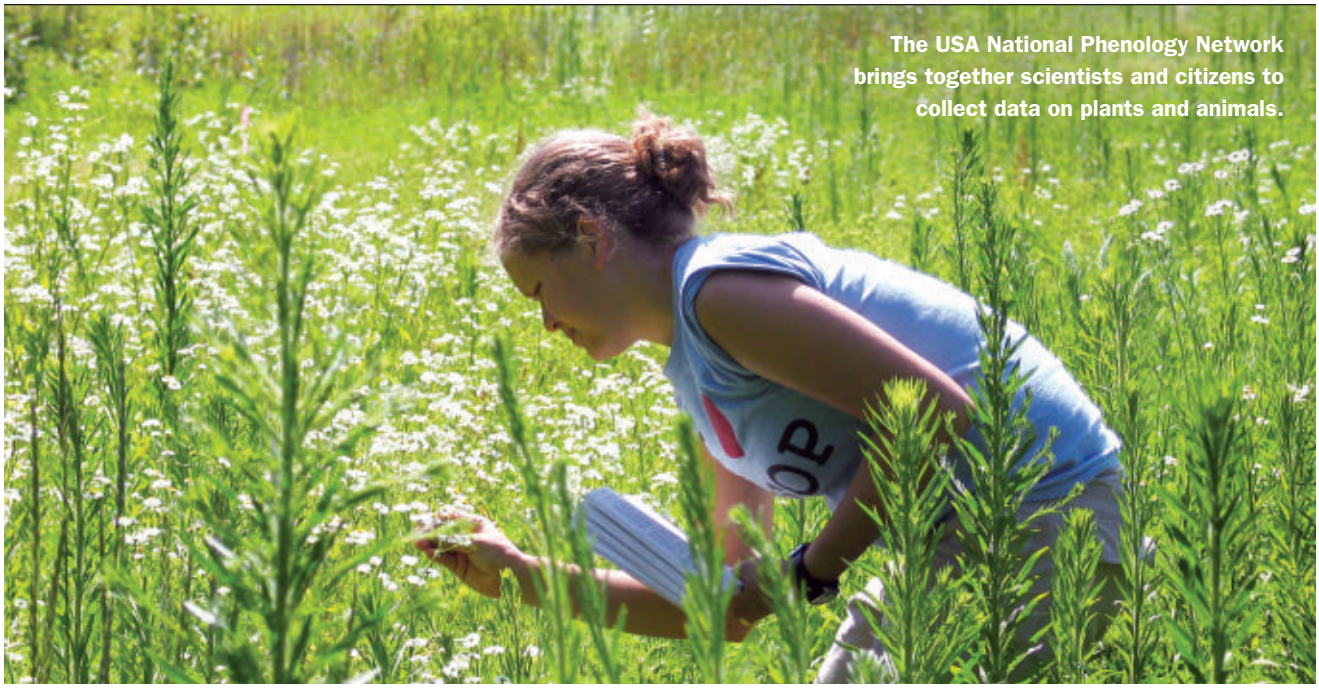

The USA National Phenology Network brings together scientists and citizens to collect data on plants and animals.

Changing seasons inspire science

Nature lovers have long tracked the timing of certain events — when plants bloom or when fish swim upstream to spawn — to answer practical questions: When are the best times to hunt and fish? When should crops be planted and harvested? These days, such homespun investigators have come to be known as citizen scientists.

Increasingly, researchers are tapping into the wealth of observations being made by citizen scientists nationwide, a data trove impossible for scientists to gather on their own (or even with a small army of graduate students). One of the largest repositories of such data is maintained by the USA National Phenology Network, founded in 2007.

Last month the organization reached a landmark of more than 1 million observations collected on hundreds of species ranging from alfalfa to Yoshino cherry, the tree whose blossoms beautify the Tidal Basin each spring in Washington, D.C. Shifts in the timing of such events are among the keenest and most widespread indicators of climate change. That makes phenology — the study of the life cycles of plants and animals and the effects of year-to-year and season-to-season climate variations — a hot topic (see Page 16).

Most of the observations cataloged by the phenology network have been made since 2009, says Jake Weltzin, an ecologist with the U.S. Geological Survey in Tucson, Ariz., and executive director of the network. But in some cases scientists won't have to wait decades for long-term records to pile up, since the organization has become a home for data collected over many years by local and regional groups. Many of these are devoted to monitoring a particular group such as lilacs, shrubs that live across much of the northern United States and whose budding and flowering have been tracked avidly by citizen scientists since 1956.

Not content to merely oversee the data gathered by others, Weltzin regularly monitors the flowering and fruiting of cacti near his Tucson home, as well as seed production of invasive grass species in a nearby wilderness area. "It gets me out of the house and into nature," he says. — *Sid Perkins*

Get involved

Anyone who is interested can gather data for use by scientists. Here are a few websites where you can learn more:

- **Did You Feel It?** allows the U.S. Geological Survey to track the effects of earthquakes. Log on to describe the strength and duration of shaking at your location, plus give details such as whether you saw building damage or rattling dishes. The data allow scientists to better predict how future quakes may affect your area. See on.doi.gov/citznQuake
- **Wildlife Health Event Reporter** lets users report sightings of sick or dead wildlife. The information helps scientists detect and contain disease outbreaks that may pose a health risk to wildlife, domestic animals or people. See bit.ly/citznWildlife
- **Citizen Science Central** is maintained by researchers at Cornell University to help citizen scientists find and participate in projects or design their own, with guidelines for everything from choosing a topic and forming a team to analyzing data and disseminating results. See bit.ly/citznCentral
- **Nature's Notebook** is run by the National Phenology Network and lets people share observations of the timing of flowering, animal migrations and color changes in leaves. See bit.ly/citznNature

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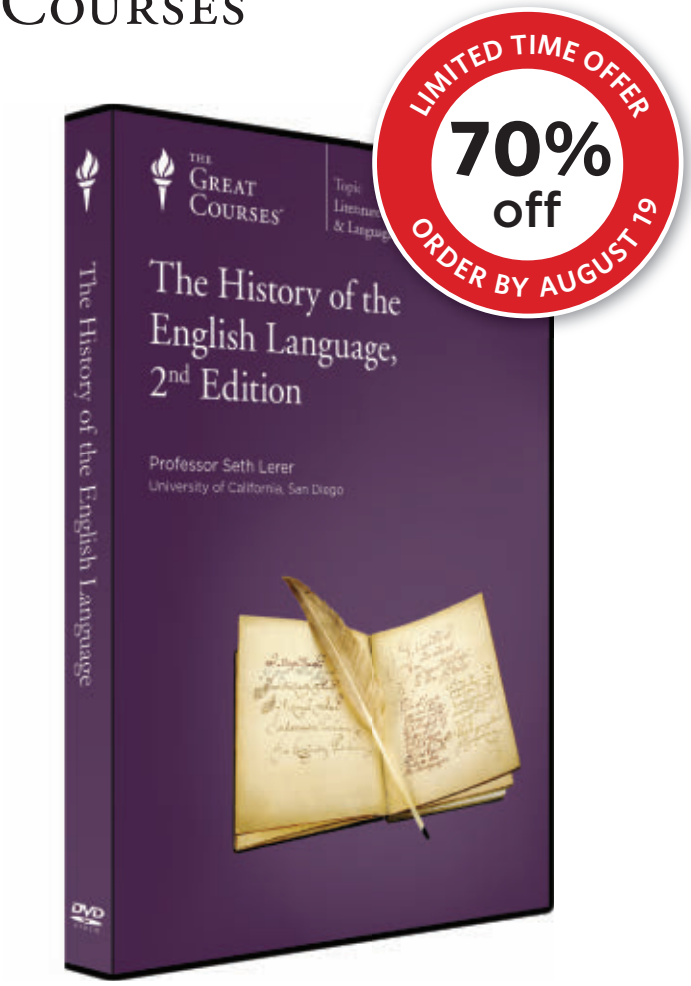

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