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ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ OCTOBER 8, 2011

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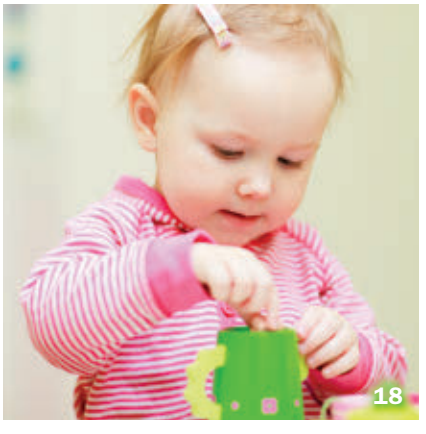

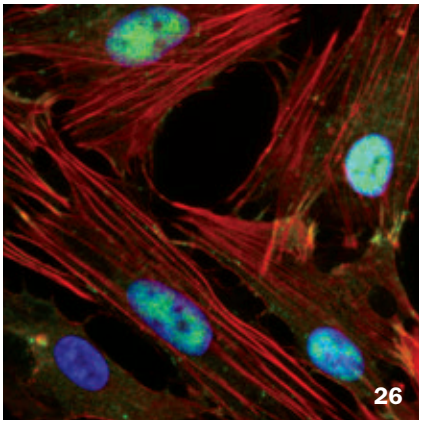

ScienceNews

In The News

Features

Departments

COVER The pearly ice crust of the Saturnian moon Enceladus may hide a refuge for alien life in the outer solar system. *NASA, JPL, Space Science Institute*

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FROM THE EDITOR

For making better bets, brains depend on Bayes

Life is all about playing the odds.

Making choices is seldom an exact science. Usually you can't compute all the possible ramifications of deciding on one course of action or another. You have to guess which is best. It boils down to assessing the likelihood of various possible outcomes for a given decision, weighing current evidence in the light of previous experience.

Fortunately, brains are pretty good at rendering such probabilistic judgments. That's because brains are Bayesian.

Bayesianism is not a disease named for the doctor who first diagnosed it, but a mathematical philosophy named for the English clergyman who first articulated it. The Rev. Thomas Bayes, in a paper published in 1764 (three years after he died), described mathematical methods for combining expectations from experience with new data to compute a probability. While widely accepted for a while, the Bayes approach was held in disrepute for much of the 20th century, thanks to the superior PR apparatus of a competing statistics philosophy known as frequentism.

Nowadays Bayesian statistics is enjoying a resurgence in popularity, thanks to its superiority in actually doing statistics. (If you're a subscriber to *Science News*, you can read more about that in my column, available at http://bit.ly/SNBayesian, from the September 26 issue of *Science News Prime*.) But in a sense, Bayesian statistics has been the most popular form of influential reasoning all along, extending back long before Bayes was born. As Laura Sanders reports on Page 18, the human brain itself seems to observe the Bayesian prescription for mixing experience with new evidence to produce accurate guesses about probabilities. Scientists have suggested that brains employ Bayesian methods in all sorts of tasks, from performing visual searches to solving simple math problems.

It may very well be that the process of science itself — the gathering of experiences about the world leading to explanations about how it works — exploits cognitive capacities that are built on Bayesian principles (even for scientists who are devotees of frequentism). Bayesian inference seems to be the best way to cope with the real world in real time. Evolution's choice of Bayesianism as the best way to bet suggests that today's textbook science ought to embrace it more enthusiastically. — *Tom Siegfried, Editor in Chief*

JIM WEBB

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Say What?

Jelly-fall*JEHL-ee-fahl* *n.* A rain of dead jellyfish onto the seafloor, similar to a "whalefall" of dead whales. In March, scientists in Norway photographed the bottom of a fjord north of Bergen; in five of 218 photographs they spotted corpses of *Periphylla periphylla* medusa jellyfish (alive, right). Shrimp swarmed the decomposing jellies, suggesting the bodies provide important nutrients in an otherwise sparse environment, the researchers report in an upcoming *Deep-Sea Research Part I*. Jellyfish numbers are up globally, and huge piles of rotting jellies have recently been found on seafloors off Oman, the Ivory Coast and Japan. —*Alexandra Witze*

Science Past | FROM THE ISSUE OF OCTOBER 7, 1961

CHEAPER WATER FROM SEA — Lower cost conversion of undrinkable sea or brackish water to potable fresh water will come closer to practicality through use of $75,000,000 appropriated by Congress for the next six years. Lowest cost achieved so far is one dollar per thousand gallons compared with the cost from ordinary sources of 30¢ per thousand. The money is for research and development in the Government's saline water conversion program. Eventual goal of the program is to supply the nation with cheap drinking water from the oceans and brackish water.... The water supply problem is becoming quite serious in the United States because of increasing water needs and pollution of available water resources.

Science Future

October 16
Comet Elenin comes its closest to Earth and may be visible with binoculars. See NASA's FAQ at 1.usa.gov/oeX6hP

October 31
Deadline for middle schoolers to enter the Future City engineering competition. Learn more at www.futurecity.org

October 18
Get hands-on at the American Museum of Natural History's Family Party in New York City. See amnh.org/familyparty

Introducing...

A previously unknown species of sea lily has turned up at seamounts more than 1,600 meters below the waves at sites off Antarctica. A shirttail cousin to the starfish, the anchored, filter-feeding organism sports what looks like a flowerlike fan above a stalk that can be a half-meter long. The 46 sparsely planted juveniles and young adults seen by scientists from France and New Zealand belong to a single species, dubbed *Ptilocrinus amezianeae*. In the September *Polar Biology*, the scientists report witnessing sea stars and urchins dining on the animals and conclude that the newly discovered population appears to be "in decline." —*Janet Raloff*

SN Online

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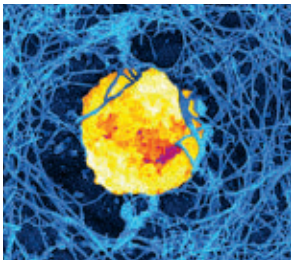
ENVIRONMENT

Plastics sloughed off clothing can pollute coastlines. See "Synthetic lint ends up in oceans."

Arctic sea ice this year was near its smallest extent on record. Read "Summer Arctic melt among worst ever."

GENES & CELLS

Natural killer cells are caught in the act of feeding poison pills (below) to tumors. See "News in Brief: Genes & Cells."

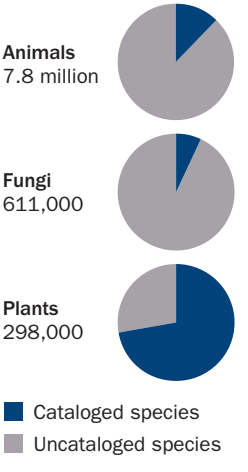


Science Stats

UNDISCOVERED SPECIES

According to a new estimate, Earth may hold 8.7 million eukaryote species, only about 1.2 million of which have been cataloged. (Examples of three major eukaryote groups shown.)

Eukaryote group and total estimated species



C. MORA *ET AL/PLOS BIOLOGY* 2011

CLOCKWISE, FROM TOP LEFT: DAVID WROBEL/VISUALS UNLIMITED, INC.; G.D. RAK *ET AL/PLOS BIOLOGY* 2011; DAVID BOWDEN/NIWA

“We’ve learned throughout life that smiling faces are good things.” —B.J. CASEY, PAGE 12

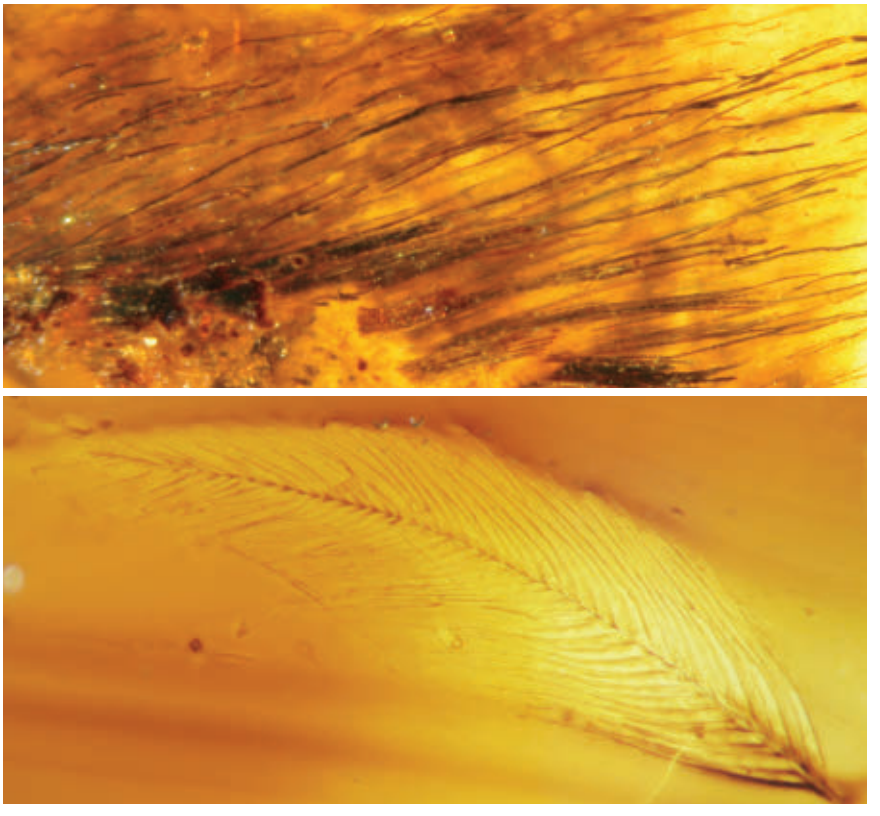
In the News

STORY ONE

Dinosaur-era feathers trapped in ancient amber

Preserved plumage reveals pigment and fine details

By Susan Milius



Eleven specimens of amber (two shown) reveal filaments and feathers preserved from the late Cretaceous period. Simple filaments (top) are believed to have covered dinosaurs. A feather barb (bottom) may have come from an ancient bird.

Bits of filaments and feathers trapped in amber 70 to 80 million years ago offer an unusually wide-ranging view of what late dinosaurs and early birds were wearing.

The 11 small, amber-bound specimens found in Canada span an evolutionary range of late Cretaceous fashion. They include what appear to be unbranched filaments — which have been proposed as the first stage of feather evolution — to bits of sophisticated, corkscrewy barbs like those seen in the wettable feathers of modern diving birds. A team from the University of Alberta describes the finds in the Sept. 16 *Science*.

Such a range has shown up squashed in rock fossils, but “we’re seeing the same thing preserved in beautiful 3-D forms,” says coauthor Ryan McKellar. “It’s preserved down to the point of having pigment, which opens up the doorway for all sorts of weird and wonderful investigations.”

To find the 11 specimens, McKellar screened more than 4,000 pieces of amber, collected from the discards of a coal mining operation near the town of Grassy Lake in southern Alberta. McKellar speculates that back in the day, the area was a salt marsh along the edge of the great seaway that ran through what is today western North America.

This trove of amber offers independent evidence that ancient feathers and even simple filaments did indeed carry pigment, says evolutionary ornithologist Richard Prum of Yale University. “I was stunned to see the level of detail preserved,” he says.

How feathers evolved has roused heated debate in recent years, as paleontologists have reported finding compressed-rock fossils of dinosaurs with remnants of filaments or feathers (see Back Story, Page 6). Well-preserved dinosaur fossils such as *Anchiornis* even show modern-looking feathers with small barbs branching from a central shaft. All but the most complicated asymmetrical flight feathers have shown up so far in dinosaurs, Prum notes.

Flight demands a lot of strength and aerodynamic specialization from a feather, so paleontologists have been spinning scenarios for what benefits might have favored the beginnings of fluff that was still useless for flying.

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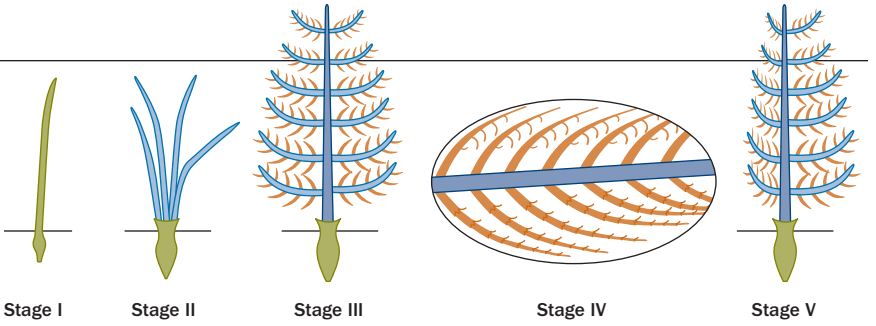
Simple filaments or clusters of filaments, potential early stages of feather evolution that couldn't heave an animal off the ground, might have been of use for insulation or courtship displays. Fancier structures that weren't flight-capable may have given an aerodynamic boost for animals rushing up steep slopes.

A few fragments of ancient feathers or protofeathers have been found in amber before, including bits from Lebanon, France and New Jersey. But none of the previous finds from dinosaur times have shown the diversity of the newly described assemblage, McKellar says.

He and his colleagues found not only what looks like an unbranched filament but also what has been proposed as a possible second stage in feather evolution, a cluster of filaments. Prum ranks the second-stage feathery bit as "really great" and convincingly identified, but admits to nagging reservations about how definitively the simple filament can be linked to a dinosaur or bird instead of some other source of debris snagged in amber.



Researchers suggest feathers evolved from single (stage I) then multiple (stage II) filaments that later developed a central shaft (stage III) covered in barbs and barbules that further differentiated and branched (stages IV and V). Scientists have found specimens in amber from stages I, II, IV and V of feather evolution.

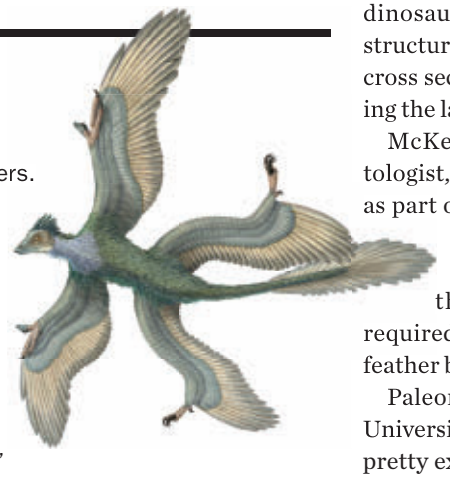
A separate, striking amber specimen shows a birdlike feather branching into secondary twigs, or barbules, with hooklets like those in modern bird feathers that zip together side-by-side barbules to make a tight, interlocked surface. Barbules on another specimen spiral at the base, a feature that allows a feather's elements to uncoil and pick up water. Such feathers on a modern waterbird ease diving by reducing trapped air, and they allow parents to soak their feathers in water and then ferry the drink back to chicks. (McKellar notes that researchers know a lot about details of modern bird feathers, thanks in large measure to the aviation industry's interest in identifying what species get sucked into airplane engines.)

None of the amber-trapped feathers had original owners attached, so the researchers can merely speculate that the simpler specimens might be from dinosaurs and the more complicated structures from birds. "It's a really neat cross section of what had plumage during the late Cretaceous," McKellar says.

McKellar, an invertebrate paleontologist, found most of the feather bits as part of a Ph.D. project searching for tiny, amber-encased wasps less than 3 millimeters long. Under the high-resolution scrutiny required to find the insects, miniature feather bits showed up, too.

Paleontologist Jakob Vinther of the University of Texas at Austin says he was pretty excited when he heard McKellar talk about the amber fossils. Vinther has explored microscopic color-generating features of fossil feathers and has even reported signs of iridescent color. He tried to persuade McKellar to give up some small bits of his specimens for examination by scanning electron microscope. But McKellar, who averaged a feathery find every 360 specimens or so, says he's not ready to sacrifice any of the samples just yet. ■

Back Story | FEATHERS ROCK



Depending on who's counting, rock fossils of about 15 genera of nonbird dinosaurs have revealed feathers. Add in fossils with less direct evidence of feathers, such as knobs on bones where quills could have attached, and the number soars into the 20s. Most of these marvels have entered the scientific literature since 1996, when a small but startling *Sinosauropteryx* (illustrated below) fossil was described as a bird. Paleontologists later hailed it as a dinosaur despite patches along its spine of short, simple filaments, what's now called "dinofuzz" and proposed as the first stage in the evolution of modern bird feathers. More recently described dinosaur fossils such as *Microraptor gui* (illustrated above) have featured more evolutionarily complex feathers with central shafts. In 2010, a research team in China even reported evidence that a *Similicaudipteryx* species replaced its feathers in birdlike molts. And a feathered fossil flap has arisen about whether *Archaeopteryx*, long touted as the first known bird, was actually a dinosaur with feathers. These glimpses of feathers on what were once believed to be scaly reptiles have reinvigorated the notion, first proposed in 1868, that modern birds evolved from the celebrity carnivore lineage of theropod dinosaurs. —*Susan Milius*

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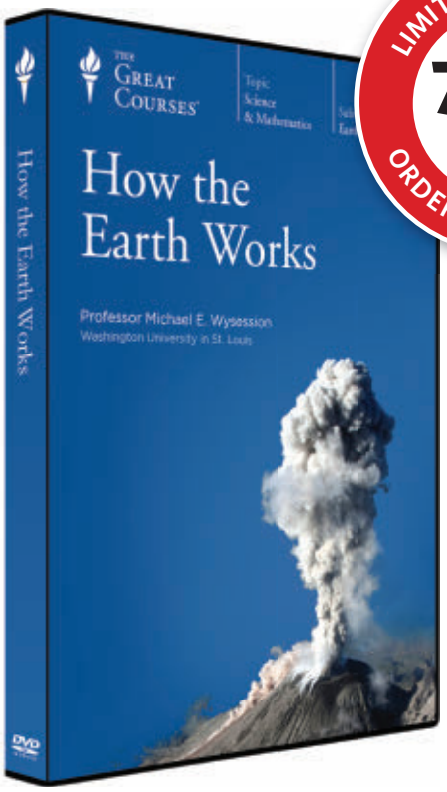

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Atom & Cosmos

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Super-Earths — dense or fluffy

Exoplanets of a certain size apparently come in two types

By Nadia Drake

With exoplanets almost as numerous as fireflies on a midsummer's eve, two top planet-finding missions disagree over the abundance of low-mass planets that are heavier than Earth but lighter than Neptune.

The Swiss-led HARPS mission suggests that between 30 and 50 percent of sunlike stars in the solar neighborhood host super-Earths and sub-Neptunes. But NASA's Kepler mission finds that these planets circle roughly 15 percent of the stars in its far-flung field of view.

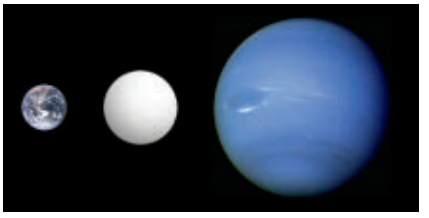
That discrepancy is of great interest, because the number of planets in the weight class just above Earth hints at how many bodies of terrestrial proportions are likely to be discovered.

But a new report suggests there may not be a discrepancy at all.

"We know the Geneva team does a good job observing, and they have a good technique. And we know the Kepler telescope is working beautifully. So we wanted to see if there was a plausible, believable way in which you could have the difference between those two surveys," says Greg Laughlin, an astronomer at the University of California, Santa Cruz.

In a paper posted online August 30 at arXiv.org, he and UC Santa Cruz graduate student Angie Wolfgang propose that there are two kinds of low-mass planets out there, one of which is more amenable to discovery by HARPS.

Laughlin and Wolfgang produced a simulation based on the HARPS data. In it, they created a population of planets between one and 17 Earth masses around the more than 100,000 stars being monitored by Kepler and gave the virtual planets varying characteristics and orbital periods between one and 50 days. When peppered with two distinct kinds of planets in the size range — one rocky and dense, the other gaseous and fluffy — the simulation mimics Kepler's data. "You can explain the results of those surveys if you have these two distinct populations," Laughlin says.



Two major exoplanet surveys have disagreed on the abundance of distant planets with masses that fall between Earth's (left) and Neptune's (right).

HARPS searches for distant planets by looking for the telltale signs of an orbiting planet tugging on its host star in what's called a radial velocity survey. Kepler uses the transit method, monitoring a star field for blips in brightness caused by a planet briefly blocking some of the star's light. These different methods can bias the types of planets detected — heavier planets tug more on their stars, and bloated planets with bigger radii block more light.

Ideally, densities for detected planets could be found by using both methods, but that often proves tricky. Two super-Earths that have been detected using both methods — CoRoT-7b and GJ 1214b — have similar masses but different densities. Both are examples that fit well with Wolfgang and Laughlin's ideas, says Andrew Youdin of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass.

Caltech planetary astronomer John Johnson notes that both surveys suggest that there are lots and lots of planets out there, and some might be quite familiar. "Kepler's been telling us that the local universe is teeming with Earths," he says. "They're just all over the place. We need to go out and find them."

Chase continues for a lighter Higgs

Latest estimates narrow target for mass of elusive particle

By Devin Powell

In the hunt for the Higgs boson, the world's most powerful particle collider has tightened the net. New data from CERN's Large Hadron Collider near Geneva narrow the range of allowable masses for the hypothetical particle, whose existence would confirm the mechanism thought to give mass to other particles.

To fit with the standard model of particle physics, the Higgs must now be lighter than 145 billion electron volts, or GeV, team members from LHC's ATLAS and CMS experiments reported August 22 in Mumbai, India, at the International Symposium on Lepton Photon Interactions at High Energies.

This new limit goes beyond previous results from the Tevatron at the Fermi National Accelerator Laboratory in Batavia, Ill. — which directly excluded 156 to 177 GeV by looking for debris left behind when the Higgs breaks down, and indirectly ruled out masses above 185 GeV.

"We've now confirmed with direct searches that the mass of standard model Higgs, if it exists, is light," says CERN's Fabiola Gianotti, a spokeswoman for ATLAS.

As it runs out of room to hide, the Higgs is still playing hard to get. Faint hints of the Higgs seen at the LHC in July — particles with energies in line with a lighter Higgs — have grown fainter in the new LHC data. Still, CERN physicists expect to discover or rule out the existence of the Higgs in the next two years.

ALDARON/WIKIMEDIA COMMONS

Genes & Cells

"So far there's really no evidence that probiotics affect emotions in humans." —EMERAN MAYER

Belly bacteria can boss the brain

Gut microbes lower stress hormones and anxiety in mice

By Tina Hesman Saey

Friendly intestinal bacteria not only keep the gut happy, they may help keep their host happy, too, a new study in mice finds.

Mice fed broth fortified with a type of gut bacteria called *Lactobacillus rhamnosus* behaved less anxiously than mice fed broth without bacteria. The observed behavior changes were accompanied by differences in levels of a brain-chemical sensor and stress hormones.

The bacteria telegraph these brain-chemical and behavior-changing messages via the vagus nerve, which connects the brain stem to other organs, researchers report online August 29 in the *Proceedings of the National Academy of Sciences*.

Some studies have suggested that changing the mix of bacteria in the intestines could influence behavior. The new research investigates how those changes may come about, says Paul Patterson, a neuroimmunologist at Caltech. "Most people haven't gone that far to look at what's happening in the brain," he says.

The research team — led by John Bienenstock of McMaster University in Hamilton, Canada, and John Cryan of the University College Cork in Ireland — looked at the mice's brains to examine levels of a protein that senses and responds to an important chemical messenger called GABA. Mice fed bacteria-containing broth had higher levels of the GABA receptor protein in some parts of the brain and lower levels in other parts than did mice fed sterile broth.

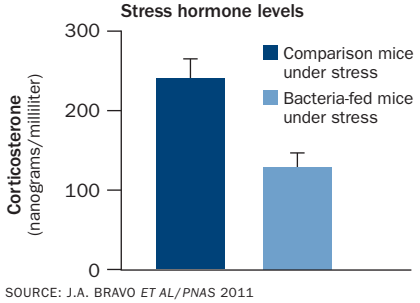
Mice usually stay close to walls, but ones that consumed the microbe spent more time in open spaces in a maze — a measure that the mice are less anxious than usual. The researchers also gave the mice a stress test by forcing the animals to swim in a water tank. Stressed mice that had eaten *L. rhamnosus* had lower levels of stress hormones than did mice that ate broth alone.

When the scientists severed the vagus nerve, the mice no longer had altered levels of the GABA receptor and didn't exhibit behavior differences, indicating that nerve is probably the major route gut bacteria use to transmit information to the brain. The vagus nerve "is the obvious route, but that's not to say it's the only route," says Bienenstock. Messages may also be transmitted through other nerves or through chemicals in the blood. The researchers still don't know what sort of message the bacteria send to the brain or whether bacterial supplements can make a difference in regulating people's behavior.

Mouse experiments hint that gut bacteria could play a role in a wide variety of brain and psychiatric disorders, such as depression, autism and schizophrenia.

But, "one has to be cautious. This is exciting science in rodents, but you can't just extrapolate to humans," says Emeran Mayer, a gastroenterologist and neuroscientist at UCLA who wasn't involved in the study. Companies that make probiotics — beneficial bacteria sold as pills or in food — hope the products can help relieve a variety of conditions in people, but little data exist, Mayer says. "So far there's really no evidence that probiotics affect emotions in humans." ■

Bacteria ease stress Mice forced to swim in a tank get stressed, but a diet that includes a bacterium called *Lactobacillus rhamnosus* lowers levels of a stress hormone.



SOURCE: J.A. BRAVO *ET AL*/*PNAS* 2011

E. FELICIANO

NEWS BRIEFS

Virus gene turns gypsy moth caterpillars into climbers

Scientists have discovered a gene that baculoviruses use to hijack gypsy moth caterpillars' brains. When infected with the virus, the caterpillars become climbers, scaling the tree on which they live. At the top, the caterpillars die, liquefy and rain down viruses on other gypsy moths. Now researchers at Pennsylvania State University in University Park and colleagues have discovered that a baculovirus gene called *egt* makes the caterpillars seek the heights. Viruses lacking the gene still kill, but the caterpillars stay down at the base of the tree, the researchers report in the Sept. 9 *Science*. The *egt* gene produces an enzyme that inactivates one of the caterpillar's molting hormones and leads to climbing. —*Tina Hesman Saey*

Endangered stem cells

Reprogrammed stem cells from two of the world's most endangered species may help bring them back from the brink of extinction. Using frozen adult skin cells from an endangered primate called a drill and from a northern white rhinoceros, scientists coaxed the cells into an embryonic stem cell–like state. The stem cells may one day be used to create eggs and sperm for breeding programs. It took many failures before the researchers succeeded in making the cells from a male drill named Loon and a female rhino named Fatu, the researchers from UC San Diego, the Scripps Research Institute and the San Diego Zoo report online September 4 in *Nature Methods*. —*Tina Hesman Saey*

Life

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Die-off fueled by acidifying oceans

Mass extinction may trace partly to changes in water's pH

By Alexandra Witze

The question of what killed most life on Earth 250 million years ago is a veritable *Murder on the Orient Express*, with multiple characters all dealing part of the deathblow. Now, scientists have learned how one of the assassins — acid — could have performed its part of the deed.

High levels of atmospheric carbon dioxide would have turned the oceans more than acidic enough to kill off marine critters, a computer simulation indicates.

"This would have been another stressor in the system that might have pushed things toward extinction," says Alvaro Montenegro, a climate modeler at St. Francis Xavier University in Antigonish, Canada. He and his colleagues describe the finding in a paper published online August 2 in *Paleoceanography*.

At the end of the Permian period of geologic time, more than 90 percent of marine species and nearly three-quarters of terrestrial species vanished. Leading suspects in the die-off include oxygen-starved oceans, a belch of hydrogen sulfide from the deep, a shutdown of major marine nutrient cycles and massive volcanic eruptions.

Using a computer model developed at the University of Victoria, Montenegro and colleagues set up nine hypothetical worlds — mixing and matching possible continental arrangements, seafloor topographies and levels of atmospheric carbon dioxide. Then the researchers fired up the model and watched how carbon flowed through the ocean and atmosphere.

At atmospheric carbon dioxide levels of 3,000 parts per million — roughly 10 times modern preindustrial levels — much of the gas dissolved in seawater, forming carbonic acid and releasing hydrogen ions. Acidity is measured on the pH scale; the lower the number, the more acidic the waters. Today's oceans have a pH of around 8.1; those in the modeled end-Permian world dropped to around 7.3 near the equator and 7.1 near the poles. That level would have made it hard for many marine organisms to use calcium carbonate to build protective shells, Montenegro says.

Today's oceans also are growing more acidic because of carbon dioxide belched into the atmosphere by fossil fuel burning and other sources. Back then, most of the gas probably came from huge volcanic eruptions in Siberia.

How quickly carbon dioxide built up in the atmosphere would have affected how acidic the ocean got, says Jonathan Payne, a paleobiologist at Stanford University. If gas concentrations increased quickly, he says, "then this model may be a reasonable representation of how climate was changing at the time." If gas built up slowly, the oceans may have been able to buffer the change in other ways.

But the model doesn't include factors such as carbon that weathered off land surfaces and into oceans — an important player in the carbon cycle, says modeler Lee Kump of Pennsylvania State University in University Park. Including such effects, he says, could better show how life's worst extinction came to pass. ■

Woolly rhinos ready for big chill

Fossils found high in the Himalayan foothills show Tibet may have been a cold testing ground where big mammals developed their cold-climate cool well before the Ice Age began. Among the treasures is the oldest fossil yet found of a woolly rhino (illustration shown), dating from about 3.7 million years ago, says Xiaoming Wang of the Natural History Museum of Los Angeles County. The complete skull and several neck vertebrae represent a new species, *Coelodonta thibetana,* of the now extinct animals, Wang and colleagues report in the Sept. 2 *Science*. A forward-leaning flattened horn convenient for sweeping aside snow while foraging for food and other characteristics offer evidence that the Ice Age giant evolved cold-weather adaptations before the big chill set in 2.8 million years ago. When the Ice Age did come, descendants of the Tibetan rhinos could have moved to lower altitudes. Fossil locations of three later woolly rhino species fit that pattern. Tibet "probably is the cradle of some of the cold-adapted species of the Ice Age," Wang says. —*Susan Milius*

JULIE NAYLOR

Earth

272.05 dollars | Gold price per ounce on Sept. 6, 2001

1,895.00 dollars | Gold price per ounce on Sept. 6, 2011

Earthly riches may be heaven-sent

Meteorites possibly peppered planet with precious metals

By Devin Powell

A meteorite maelstrom that pummeled Earth and pocked the moon with craters billions of years ago may have had a silver lining — and linings made of other metals, too.

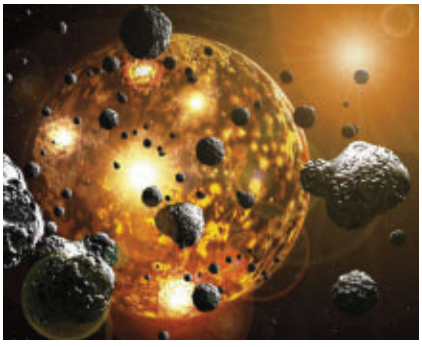
New evidence from old rocks suggests that many of the precious metals mined today were delivered to the planet by stony meteorites called chondrites in a bombardment that lasted for hundreds of millions of years.

"Adding a tiny amount of chondritic material could explain where many present-day metals came from," says Matthias Willbold, a geochemist at the University of Bristol in England, whose team reports the findings in the Sept. 8 *Nature*.

Within 50 million years of Earth's formation, much of its iron sank to the middle to form the core. Gold, platinum and some other precious metals followed.

Searching for a source that could have later replenished these metals, Willbold and colleagues looked for different forms, known as isotopes, of the metal tungsten in rocks from the 3.8-billion-year-old Isua greenstone belt in Greenland. The belt probably formed before the massive influx of meteorites that geologists call the late heavy bombardment.

Compared with the Greenland specimens, newer rocks contain lower ratios of light tungsten to standard tungsten, the team found. Chondritic meteorites don't have much of the lighter tungsten-182 compared with Earth's mantle, so meteorites mixed into the mantle over geologic timescales could have diluted Earth's younger rocks. The amount of incoming material needed to explain the tungsten discrepancy would bring enough metals to the planet to account for the quantities of those elements observed today, says Willbold.



JULIAN BAUM/TAKE 27 LTD

Meteorites that pummeled Earth billions of years ago may have deposited the precious metals mined today.

Humans

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Willpower may be a lifelong trait

Tots' capacity to postpone gratification lasts decades

By Laura Sanders

Forty years after succumbing to a mouthwatering marshmallow as a child, middle-aged adults still have a hard time resisting temptation, a new study finds. The results, published in the Sept. 6 *Proceedings of the National Academy of Sciences*, suggest that willpower is stable over a person's lifetime.

"I'm impressed," says psychologist and neuroscientist Bernd Figner of Columbia University, who wasn't involved in the experiments. "It really is a unique study."

The experiment began in the late 1960s at Stanford University's Bing Nursery School, where more than 500 4-year-olds were given the dreaded "marshmallow test." The preschoolers sat in a room with only a sweet, gooey marshmallow to keep them company. A child could eat the single marshmallow or hold out for 15 minutes to get two. Some kids couldn't resist and gobbled the treat quickly, while others held out and doubled their reward.

Study coauthor B.J. Casey of Weill Cornell Medical College in New York City and her colleagues wanted to know whether the holdouts displayed the same kind of willpower 40 years later.

Fifty-nine of the original subjects — now in their mid-40s — came back for more tests. This time around, researchers tested willpower in a different way: Instead of a marshmallow, the researchers used feel-good pictures of smiling faces. "We've learned throughout life that smiling faces are good things," Casey says.

Participants were asked to press a button whenever they saw a particular face. The targets flashed frequently, and people grew accustomed to mashing the button quickly. But every so often, a smiling face they were meant to ignore came into the mix, forcing the participant to squelch the desire to push the button.

People who let the marshmallow get the better of them as children had a harder time curbing their impulse to push the button than the adults who held out against the marshmallow as kids, the team found.

Brain scans of 26 participants revealed that activity in part of the brain's frontal lobe — a region known to be important for exerting control — was associated with temptation resistance.

Oldest hand axes discovered

African finds offer glimpse of early toolmaking complexity

By Bruce Bower

East Africa has yielded the oldest known stone hand axes and picks, examples of what researchers call the Acheulian industry. Acheulian implements unearthed at Kenya's Kokiselei site date to 1.76 million years ago, slightly older than previous finds, say geologist Christopher Lepre of Rutgers University and his colleagues. The carefully shaped, double-edged hand axes and picks lay among much simpler tools — sharp flakes pounded off stones, the scientists report in the Sept. 1 *Nature*.

These finds underscore suspicions that earlier tools known as the Oldowan industry did not get supplanted by hand-ax making, Lepre says. *Homo erectus*, a possible direct ancestor of modern humans, made Acheulian tools and perhaps Oldowan ones as well at Kokiselei, his team suggests.

"If Acheulian tools gave hominids an edge in Africa, then perhaps groups lacking that technology were forced to find resources elsewhere," Lepre says.

In line with that proposal, other researchers have unearthed *H. erectus* fossils at Dmanisi, a West Asian site as old as Kokiselei, along with simple chopping stones, but no hand axes. It remains unsettled whether *H. erectus*, which first appeared around 2 million years ago, evolved in Africa or Asia.

Some sets of Oldowan and Acheulian artifacts look very similar, implying that the same hominid species could have produced both tool types, says Naama Goren-Inbar of the Hebrew University of Jerusalem.

Fossils are needed to confirm that *H. erectus* made both kinds of implements at Kokiselei, says John Shea of Stony Brook University in New York.

A stone hand ax (shown from different angles) dating to 1.76 million years ago comes from the earliest known culture to have made such implements.

P.-J. TEXIER, © MPK/WTAP

4–6 percent Denisovan-derived DNA in some Melanesians | **4 percent** Neandertal-derived DNA in some Europeans

Humans benefited by interbreeding

Important immune system DNA came from Neandertals

By Rachel Ehrenberg

Sleeping around can expose you to diseases, but, at least in the course of human evolution, it may help you fight 'em. New research suggests that thousands of years ago humans acquired important immune system genes via liaisons with some of our extinct hominid cousins, the Neandertals and Denisovans. These dalliances may have allowed modern humans to persist in regions where unfamiliar pathogens may have otherwise killed them.

Many modern human populations appear to have the same versions of certain immune system genes found in those archaic relatives, a team of researchers reports online August 25 in *Science*. The Neandertal and Denisovan versions are most prevalent in modern populations in Europe and Asia. Because modern African populations harbor little to none of these archaic gene variants, the discovery suggests that humans acquired them after heading out of Africa and running into Neandertals and Denisovans in Europe and Asia.

"It's amazing stuff," says Daniel Geraghty, a specialist in genetics and immunology at the Fred Hutchinson Cancer Research Center in Seattle. "They have done a really great job of weaving together facts to come up with a very plausible and very powerful story of what might have happened to the human species as it expanded out of Africa."

Previous research suggested that humans were interbreeding with both Neandertals and Denisovans, a closely related species known from a fossil finger bone found in a Siberian cave. Modern Eurasian genomes contain up to 4 percent Neandertal DNA, and the DNA of Melanesians of Papua New Guinea is 4 to 6 percent Denisovan (*SN: 6/5/10, p. 5; SN: 1/15/11, p. 10*).

Laurent Abi-Rached of Stanford University School of Medicine and colleagues decided to home in on three particular immune system genes called HLA genes, which help the body recognize foreign, potentially dangerous invaders. HLA matches in donors and recipients are crucial for organ transplants.

The results indicate that humans were definitely producing offspring with Neandertals and Denisovans.

Using the genetic blueprints of three Neandertals, the one Denisovan and present-day genetic information from bone marrow/stem cell donor registries, the researchers compared the frequencies of various versions of the HLA genes. Computer simulations assessed whether the observed frequencies were unusual.

The results indicate that humans were definitely producing offspring with Neandertals and Denisovans. In some instances those offspring acquired archaic versions of the genes that imparted such a benefit that they eventually became widespread. One Denisovan version of an HLA gene, for example, seems to be present in 50 to 60 percent of people in China and Papua New Guinea.

Experts in evolution and genetics say the results are exciting but urge caution in interpreting the data. Because immune system genes would be subject to intense selection — having the wrong ones would be fatal — it isn't clear exactly what factors shaped the present-day genetic patterns, says David Reich of Harvard Medical School and the Broad Institute in Cambridge, Mass. Reich was a lead researcher on the previous studies that unraveled the genomes of Neandertals and the Denisovan. ■

NEWS BRIEFS

Sole evidence

Most criminals know to avoid leaving fingerprints at a crime scene, but soon footprints may also be a dead give-away. Rather than signature ridges, the sole of the foot has an identifiable pressure signature that can be used to identify someone with 99 percent accuracy, an analysis of 104 individuals reveals. The new work examined only barefoot walkers; how shoes and different gaits might alter patterns isn't clear. But the data are now easy to analyze, an international team reports online September 7 in the *Journal of the Royal Society Interface*, and foot-pressure devices are easy to install, so there may a future role for the identification technique in the security realm. —*Rachel Ehrenberg*

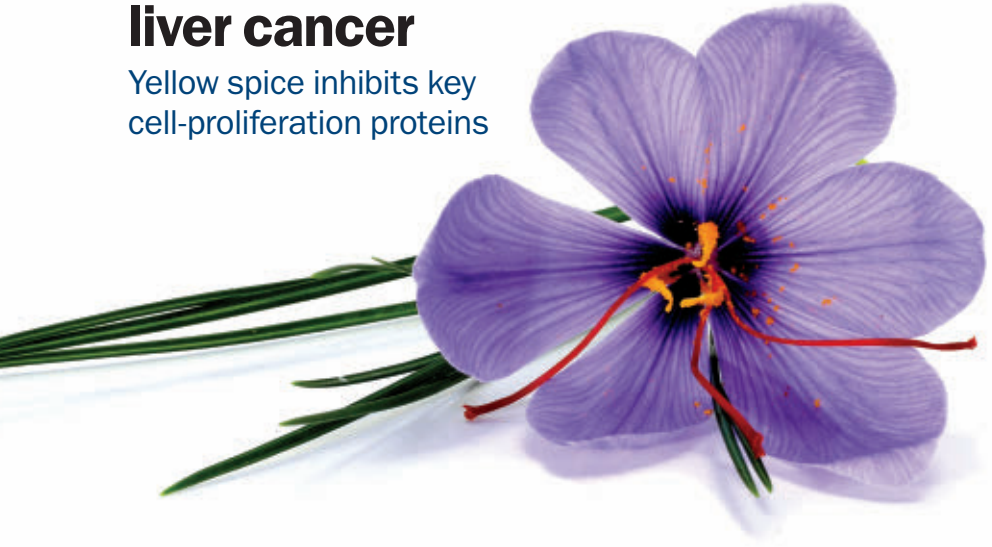
Breast-feeding gives women an edge

Mothers' milk has a mean streak. Breast-feeding mothers act far more antagonistically toward a competitor in a lab task than bottle-feeding mothers or women who have never given birth do, say UCLA psychologist Jennifer Hahn-Holbrook and her colleagues. Like mama bears and other lactating mammals, breast-feeding moms are biologically primed to protect themselves and their babies, the researchers propose online August 26 in *Psychological Science*. In the lab test, lactating women delivered what they thought were especially long and loud sound blasts to vanquished opponents in another room, yet exhibited lower blood pressure while doing so than other women did. —*Bruce Bower*

Body & Brain

Saffron fights liver cancer

Yellow spice inhibits key cell-proliferation proteins



Harvested from the *Crocus sativus* flower (shown), saffron stifles liver cancer's growth in rats and even inhibits the proliferation of human liver cancer cells.

By Nathan Seppa

Best known as a food seasoning and dye, saffron can also stifle liver cancer in rats, tests show. In a paper in the September *Hepatology*, researchers report that the spice suppresses a slew of known cancer-related compounds and boosts several beneficial ones.

Saffron is an expensive spice made from the *Crocus sativus* flower. Past studies have hinted that it has benefits against depression, inflammation, memory loss and as an antioxidant. Studies in animals and in human cells have even suggested that saffron can inhibit certain cancers. "But the exact mechanism of the anticancer effect of saffron is unclear," says Amr Amin, a molecular biologist at United Arab Emirates University in Al-Ain.

Brain stents don't decrease strokes

Rates of death, repeat events higher after implant procedure

By Nathan Seppa

Threading a catheter up into the brain and inserting a device that widens a dangerously narrowed artery might do more harm than good in some patients at risk of stroke. An aggressive course of medications alone appears to be safer, researchers report in the Sept. 15 *New England Journal of Medicine*.

Mesh cylinders called stents have offered cardiologists an approach to opening clogged coronary arteries that is less invasive than surgery. Now researchers are using a new generation of tiny stents to tackle similarly narrowed vessels in the brain. Federal regulators approved a brain stent in 2005, and past studies have supported stents' effectiveness against stroke.

Researchers used the approved stent in the new trial. The team enrolled hundreds of patients at 50 hospitals who had just survived a stroke or had a transient ischemic attack, a kind of stroke that clears up within a day, says study coauthor Marc Chimowitz, a neurologist at the Medical University of South Carolina in Charleston. The average age of the patients was about 60.

Brain scans of these patients pinpointed an artery with buildup that obstructed at least 70 percent of blood flow. People with such bottlenecks are at high risk of having a stroke, because a blood clot may form at the narrowed spot and block blood flow, or a loose clot might get lodged at the pinch point. All patients received clot-busting medicines and drugs to lower cholesterol and control blood pressure.

In addition to the drug regimen, half the people were randomly assigned to get a stent to widen the narrowed brain artery. Study coordinators planned to include about 760 patients in the study, but recruitment was stopped after the researchers had enrolled only 451.

Nearly 15 percent of patients getting a stent died or experienced a stroke within 30 days of joining the study. All those strokes occurred within a week of stent placement — often on the first day. Of the patients getting medication only, less than 6 percent died or had a stroke within the first 30 days. After one year, about 20 percent of the stent group and 12 percent of the drugs-only group had died or had a stroke. The stented vessels hemorrhaged in some cases.

Translating the success seen in coronary arteries to fragile brain vessels has been tricky. "It's very attractive to think that if you can make the vessel picture look better, the patient will do better," says Walter Koroshetz, deputy director of the National Institute of Neurological Disorders and Stroke in Bethesda, Md. "But it really has to be proven."

Several companies make stents, and ongoing studies may show whether the devices can prevent strokes in some people. "I don't think the [stent] intervention approach is dead," Koroshetz says, but brain surgeons will need better stents that don't damage vessels. ■

NITO/SHUTTERSTOCK

14.7 percent | Fraction of patients getting stents and drugs who died or had a stroke within 30 days

5.8 percent | Fraction of patients on drug therapy alone who died or had a stroke within 30 days

Although the spice has been used as a folk remedy for centuries, only in recent decades has its value been tested in the laboratory. In the new study, Amin and his colleagues fed saffron to 24 rats daily for 24 weeks. Two weeks into the regimen the researchers injected the animals with diethylnitrosamine and 2-acetylaminofluorene, a chemical combination known to cause liver cancer.

Eight other rats getting a similar injection combination received distilled water instead of saffron. Six of them developed cancerous nodules on the liver during the course of the study, whereas only four of the 24 rats getting saffron developed nodules. Of eight rats that got the highest dose of saffron, none developed any nodules.

Amin says his team chose to study liver cancer because cancers that spread from other organs, such as the colon or breast, often end up there.

Saffron kept in check a cell-proliferation protein called Ki-67 and reduced other compounds linked to liver damage and oxidative stress. Oxidative stress results from an imbalance between unstable, reactive molecules called free radicals and the antioxidants that sop them up. This tilt can lead to aberrant cell growth, a precursor to cancer, Amin says. Levels of antioxidants, including one called superoxide dismutase, were restored in the rats getting saffron.

A separate series of tests on human liver cancer cells showed that saffron inhibits the action of key proteins — NF-kappa B, interleukin-8 and tumor necrosis factor receptor 1 — that contribute to cell proliferation and inflammation. Other evidence shows that saffron switches on programmed cell death in cancerous cells, a fail-safe mechanism that is often shut down in cancer.

"This is very extensive work, and the quality is very good," says Tapas Saha, a molecular biologist at the Georgetown University Lombardi Comprehensive Cancer Center in Washington, D.C.

But Saha says that scaling up these findings for treatments in people might be a challenge. Saffron must be handpicked, he notes, so the price remains high. "Saffron is such a costly material," he says, "that it's very difficult to understand how it can be a drug."

Synthetic versions of the important saffron components might be less expensive. Amin says further research may delineate those constituents. Meanwhile, the team plans to test the spice in liver cancer patients. ■

Science & Society

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Data mining finds new disease links

Migraines and hair loss among unexpected connections

By Rachel Ehrenberg

Danish scientists have devised a new way to connect the dots between diseases. Integrating data mining that extracts information from clinicians' notes with protein and genetic information can reveal connections between health problems as seemingly unrelated as migraines and hair loss, or glaucoma and a hunching back, researchers report August 25 in *PLoS Computational Biology*.

Besides generating new leads about the molecular workings of disease, the approach is also revealing a much richer portrait of each patient, says study coauthor Søren Brunak of the Center for Biological Sequence Analysis at the Technical University of Denmark in Lyngby and the University of Copenhagen.

Using the World Health Organization's codes for classifying diseases, researchers generated a map that linked more than 4,700 patients at Denmark's largest psychiatric hospital by their diagnoses. The team integrated these data with information gleaned from a text-mining algorithm that combed through 10 years' worth of clinicians' notes.

More than 800 pairs of health problems turned up more than twice as often as expected by chance. Investigations into the genes and proteins associated with some of these unusual pairs revealed previously unknown connections.

For example, the team identified nine patients diagnosed with both migraine and alopecia, or hair loss. The researchers discovered a potential cellular target of a protein that had already been implicated in hair loss by investigating the protein's connection to migraines. The scientists also realized that the gluten allergy known as celiac disease has been associated with hair loss and migraines — and also has been linked to schizophrenia.

A network depicting patient diagnoses reveals connections between, for example, diabetes (light orange, top) and hypertension (dark green, top right).

Clinical notes are a huge source of information, says Stéphane Meystre, a specialist in biomedical informatics at the University of Utah in Salt Lake City. "This approach clusters information in a much more detailed way."

El Niños may fuel civil uprisings

Food prices, unemployment may link climate to unrest

By Janet Raloff

One in five major civil conflicts since 1950 may be linked to climate extremes associated with El Niños — periods of warming lasting a year or longer in surface waters of the central equatorial Pacific, a new study finds.

Solomon Hsiang of Princeton University and his coauthors at Columbia University emphasize that they don't know what mechanism might link El Niños to eruptions of major civil unrest, which the team defines as political disputes between governments and other organized parties that claim more than 25 lives. But, the group reports in the Aug. 25 *Nature*, droughts, torrential rains and other extreme weather that tend to develop during El Niño years can devastate crop yields, leading to higher food prices and unemployment in affected nations — home to half of the world's population.

"I'm one of those people who would be generally skeptical about correlating things to climate," says statistician Andrew Solow of the Woods Hole Oceanographic Institution in Massachusetts. But the new finding makes sense, he says: In poor countries where the economy is closely linked to agriculture — and therefore the weather — failed harvests and diminishing food supplies can leave large numbers of people available to engage in civil uprisings.

Hsiang and his colleagues analyzed 234 civil conflicts that broke out within 175 nations between 1950 and 2004. In any given year, the probability that a new conflict would erupt among the 90 or so nations whose climates are vulnerable to El Niño events was 4.1 percent. That's twice the conflict rate in countries largely immune to El Niño effects.

Yaneer Bar-Yam of the New England Complex Systems Institute in Cambridge, Mass., argues that the new study is a good example "of the progress that has been made in understanding how we can predict social behavior writ large." The correlation doesn't prove that El Niño weather disruptions cause civil unrest, he acknowledges. "But a properly used and understood correlation is an important tool for understanding interdependencies in complex systems — and the world around us."

F.S. ROQUE *ET AL./PLOS COMPUTATIONAL BIOLOGY* 2011

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The probabilistic mind

Human brains evolved to deal with doubt

By Laura Sanders

$$P(h_i|d) = \frac{P(d|h_i)\,P(h_i)}{\sum_{h_j \in H} P(d|h_j)\,P(h_j)}$$

$$P(h_{foe}|d) = \frac{P(d|h_{foe})\,P(h_{foe})}{P(d|h_{foe})\,P(h_{foe}) + P(d|h_{friend})\,P(h_{friend}) + P(d|h_{family})\,P(h_{family})}$$

$$P(h_{foe}|d) = \frac{(0.8)(0.5)}{(0.8)(0.5) + (0.3)(0.3) + (0.3)(0.2)}$$

$$P(h_{foe}|d) = \frac{0.4}{0.4 + 0.09 + 0.06}$$

$$P(h_{foe}|d) = 0.73$$

Humans live in a world of uncertainty. A shadowy figure on the sidewalk ahead could be a friend or a mugger. By flooring your car's accelerator, you might beat the train to the intersection, or maybe not. Last week's leftover kung pao chicken could bring another night of gustatory delight or gut agony.

People's paltry senses can't always capture what's real. Luckily, though, the human brain is pretty good at playing the odds. Thanks to the brain's intuitive grasp of probabilities, it can handle imperfect information with aplomb.

"Instead of trying to come up with an answer to a question, the brain tries to come up with a probability that a particular answer is correct," says Alexandre Pouget of the University of Rochester in New York and the University of Geneva in Switzerland. The range of possible outcomes then guides the body's actions.

A probability-based brain offers a huge advantage in an uncertain world. In mere seconds, the brain can solve (or at least offer a good guess for) a problem that would take a computer an eternity to figure out — such as whether to greet the approaching stranger with pepper spray or a hug.

A growing number of studies are illuminating how this certitude-eschewing approach works, and how powerful it can be. Principles of probability, researchers are finding, may guide basic visual abilities, such as estimating the tilt of lines or finding targets hidden amid distractions. Other behaviors, and even simple math, may depend on similar number crunching, some scientists think.

And such advanced statistical reasoning does not require paying attention in math class. New studies suggest that 1-year-olds are already tiny probabilistic machines who, in many situations, assess statistical input and perform optimally with ease.

Studying the guesstimating brain is a new enough endeavor that no one yet knows how people developed such computational abilities. Nor do scientists know the precise brain machinery behind the math.

LEE WILLIAMS/FLICKR/GETTY IMAGES

"We're going to continue to try to understand these processes," says Eero Simoncelli, a computational neuroscientist at New York University. "It's a long road. It's going to be many decades until all of this gets worked out. But the progress is steady."

Seeing and believing

When Pouget started studying the brain's computations two decades ago, nobody thought that humans deal in probabilities, he says. Back then, researchers thought that if you want to catch a baseball, your brain computes the trajectory and spits out an exact answer, telling your body where to move the glove, he says. "Today, we say, 'No, if you have a baseball flying at you, you compute the probability of where it might be and then you place your hand to maximize the probability that you're going to catch it.'"

This shift — from studying certitude to probabilities — is largely based on the work of Thomas Bayes, an 18th century English clergyman. A claim is more reliable if initial beliefs are also included in the assessment, Bayes proposed. And these initial beliefs, known as "priors" today, can be updated as more information comes in, narrowing the range of good solutions. At its heart, the concept is simple: Learning from experience leads to better predictions.

Take a doctor faced with a medical mystery. A young boy comes into the office with a slight fever, a headache and joint pain, symptoms that could be caused by a garden-variety cold or the more nefarious Lyme disease. With no additional information, the doctor might as well flip a coin. But armed with key pieces of information — medical school tidbits and knowledge of whether the boy played in tick-teeming woods, for instance — the physician can come up with a solid diagnosis.

Though the value of considering priors is still a matter of dispute in the statistics community (*SN: 3/27/10, p. 26*), the brain is chock-full of them. And humans constantly mediate a tug-of-war between those priors and current evidence.

By showing how assumptions can lead people astray, a new study highlights how heavily the brain leans on priors. Psychologist and computer scientist Ahna Girshick of the University of California, Berkeley, along with Simoncelli and another colleague, recently asked people to assess the relative tilts of sets of fuzzy lines on a computer screen. The task is like trying to say which way, on average, a handful of dropped toothpicks point.

The volunteers' performance suggested that they thought the lines were more aligned with the horizontal or vertical axes than they actually were, the team reported in the July *Nature Neuroscience*. That assumption may exist for a very simple reason, says Girshick. "In nature you see these very strong verticals because of trees, and you also see horizon lines and flat surfaces to walk on," she says. "We've all been raised on planet Earth, and there are mathematical structures to the world around us that you can measure."

What's more, the researchers could strengthen the misperception by changing the conditions: When the arrays of lines varied more, people showed an even greater bias toward the horizontal or vertical directions. Greater doubt led to a stronger reliance on preconceived ideas.

Scientists don't yet know what physical hardware in the brain might be performing such Bayesian reasoning, but simulations suggest variations in nerve cell behavior might be responsible for these seemingly complex calculations. "It seems like sophisticated math," Girshick says. "But it could be quite simple."

Some nerve cells respond strongly to horizontal or vertical lines, while others don't give those orientations special attention. "You get this Bayesian-like behavior simply by the fact that you have this nonuniformity in the brain," Girshick says.

Bomb amid batteries

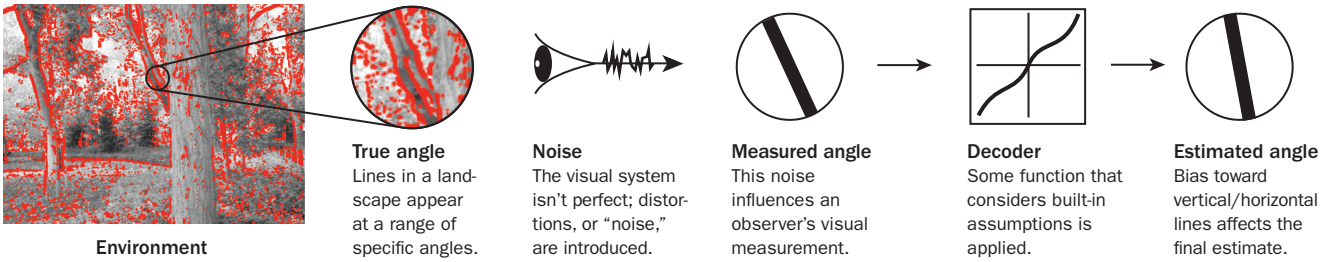
As any airport security screener knows, spotting a bomb among a steady stream of computer batteries, alarm clocks and blow-dryers is notoriously difficult. But in the case of this visual challenge, called a visual search, the Bayesian brain appears to perform surprisingly well.

Given the incomplete information that humans get from their retinas, people's visual search skills are remarkable, Pouget says.

"Visual search happens absolutely all the time," he says. "We thought this is exactly the kind of task where a probabilistic approach would be great." In a recent study, he and his team had participants watch a computer screen for a quick flash of a target — a previously seen line tilted at a particular angle. On the screen, this line was surrounded by distracting objects. Participants reported whether the target was there or not, and how confident they were in the answer.

When the target blended in with the background and the distracters were nice and bright, people grew worse at

Bayesian-based brains Though they don't yet have a clear idea of how the brain does the calculations needed to compute probabilities based on built-in assumptions, scientists do have some sense of the steps involved in encoding and decoding an environmental stimulus.



A.R. GIRSHICK *ET AL/NATURE NEUROSCIENCE* 2011

recognizing the target, assuming that it was simply not there. But they grew worse in a very particular way. People's behavior closely mirrored what Bayesian math predicted, the team reported in the June issue of *Nature Neuroscience*.

"A visual search starts involving pretty complicated mathematics," Pouget says. Yet in the study, the human subjects were "as good as they could possibly be."

Now the team is wondering just how good humans' Bayesian thinking can get. "The lab is on a quest to find out, 'OK, where do we break down? How much complexity do we have to put in the task before we can no longer come up with the optimal solution?'" Pouget says. "And so far we haven't found where that boundary is."

Psychologist Wilson Geisler of the University of Texas at Austin prefers an approach that starts with the outside world. His team uses carefully calibrated cameras to capture a scene and range-finders to measure the distance from the cameras to each point in the scene and the brightness of the light coming from each of those pixels. These tools allow the researchers to construct an exact mathematical description of the natural world.

"We try to measure the actual 3-D world, and then we try to learn how you would estimate the shape or distance of an object," Geisler says. With this precise mathematical description of the world, Geisler then builds a theoretical tool that mimics the behavior of a perfect Bayesian-thinking human inhabiting that world — an "ideal Bayesian observer."

By comparing flesh-and-blood humans against this "ideal observer," Geisler and his colleagues are getting a sense of how people stack up. They are "almost perfect," Geisler says. But before cockiness sets in, Geisler points out that in these studies perfection doesn't mean always being correct. For instance, people judging whether two patches of green behind a mushroom belonged to the same leaf or different ones would get worse at the task as the mushroom grew bigger and hid more of the scene. Unreliable information leads people astray in a way that Bayesian math predicts.

In a study published last year in the *Journal of Vision*, Geisler and colleagues showed participants close-up pictures of leaves photographed at a nearby botanical garden. People's performance at distinguishing two overlapping leaves in patches from a two-dimensional image mirrored the performance of an ideal observer. Participants seemed to operate with existing knowledge of how to visually unjumble a pile of leaves.

In a way, it's self-evident that humans rely on existing knowledge. A brain that didn't rely on its experiences would be a pretty pathetic brain. "You could argue that it would be a little strange if we were bad at it," Geisler says. "It's something that we have enormous experience with, evolutionarily. The same problem has been there for a billion years. But nonetheless, the statistics are complicated."

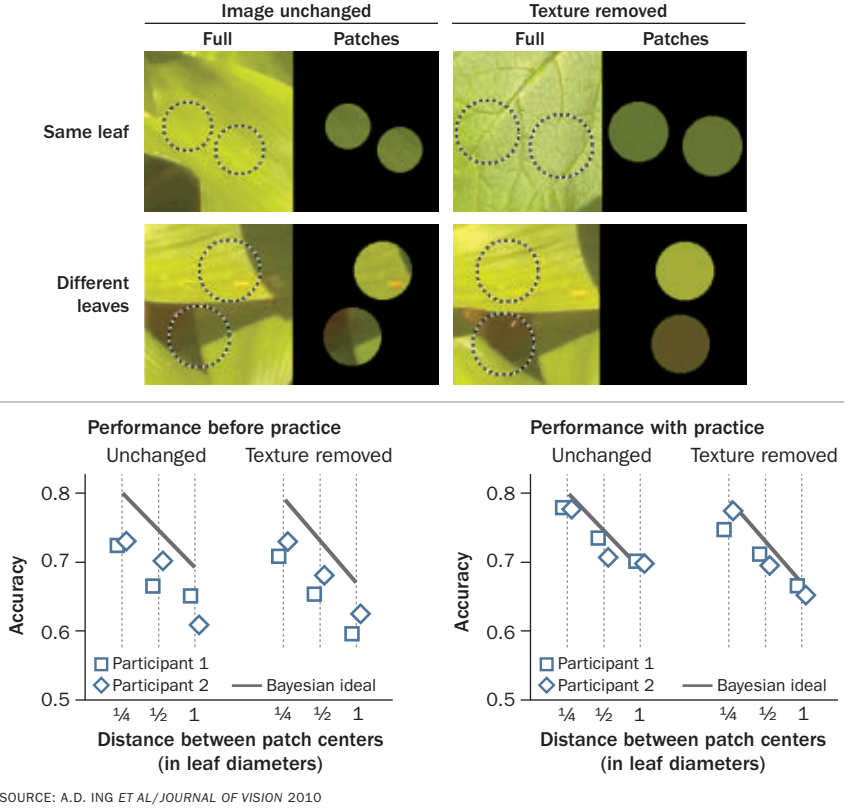
Parsing these statistics isn't just a task for the visual system. So far, some scientists have turned up hints that movements, smells, hearing, cognition and the ability to perform easy addition problems may be based on Bayesian techniques. And these abilities might be present well before a child learns 2 + 2.

A's, Bayes, C's

By studying babies and young children, scientists can test whether probabilistic reasoning is present before life experiences begin sculpting the mind. Babies haven't been alive long enough to develop strong beliefs about how the world works. If babies act Bayesian, then they may have been born that way.

Sixteen-month-olds can make correct assumptions when faced with complicated data, cognitive scientists Laura Schulz and Hyowon Gweon of MIT reported June 24 in *Science* (*SN Online: 6/28/11*). In the study, babies watched as experimenters pressed a button on a toy, causing music to play. In some cases, the toy worked beautifully the first time each experimenter pushed

Optimal performers Study participants who were shown intact or distorted patches of leaf images (top panel), and were asked to determine whether the patches came from the same leaf or different leaves, performed nearly as well as an ideal Bayesian observer (gray line in graphs).



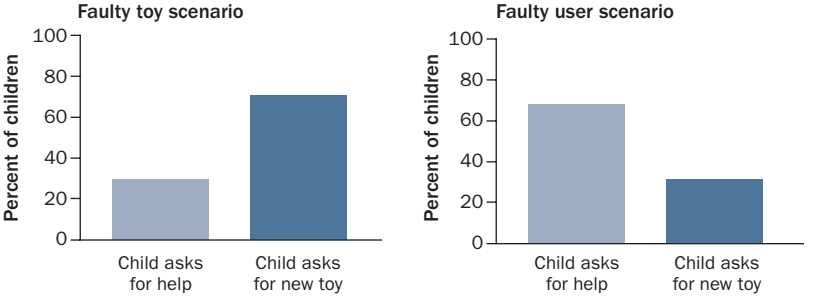
SOURCE: A.D. ING *ET AL/JOURNAL OF VISION* 2010

LEAF IMAGES: A.D. ING *ET AL./JOURNAL OF VISION* 2010

BLUEORANGE STUDIO/SHUTTERSTOCK

Baby rationale Babies can think in probabilistic ways. After seeing two researchers both succeed and fail in using a sound-making toy, a baby who then fails with the same toy is likely to think the toy is faulty and tends to go for another (below, left). But when one researcher fails and a second succeeds, the baby more often takes the blame and asks for help (right).

SOURCE: H. GWEON AND L. SCHULZ/*SCIENCE* 2011



the button, but fritzed out the next time. This created the semblance of a faulty toy. In other cases, the toy worked well for one experimenter but never worked for another, suggesting that the toy was fine but the second experimenter was a poor operator.

When the babies were handed the toy that seemed like it was faulty, they quickly reached for a different toy. But when the babies thought they themselves might be to blame (when they witnessed the second experimenter fail with the toy and then they failed themselves), they handed the toy to a nearby parent in a plea for help.

By assessing others' toy travails and applying that knowledge to their current problem, babies displayed very sophisticated reasoning, Schulz says. "As early as we can test, babies are using things that are consistent with probabilistic models," she says. "Babies are sensitive to the statistics of the environment."

Instead of looking for signs of probabilistic reasoning in young humans, some scientists are looking for signs in other species. A recent study in owls suggests that aspects of their brains also follow Bayesian rules.

Though owls are admirable hunters, they typically don't hear sounds that come from areas in the periphery as well as sounds coming from the front. To explain this deficit, Brian Fischer of École Normale Supérieure in Paris and José Luis Peña of the Albert Einstein College of Medicine in the Bronx, N.Y., turned to Bayesian math.

The team devised a statistical model of auditory processes with the assumption that owls may have evolved to assign less importance to signals coming from the periphery because hunting something at their backs might be too costly. A turning motion might scare prey away, for instance. In tests, Bayesian models closely predicted this actual owl behavior, the researchers reported in the August *Nature Neuroscience*.

In the owl's auditory system, this bias toward hearing objects right in front may come preinstalled. Likewise, babies may be hardwired to quickly infer whether they are to blame for a nonworking toy.

Where, when and how these pieces of prior knowledge get filed away in the brain is still a mystery. Some scientists think priors — and the ability to use them — were built into brains over the course of evolution.

"Biological systems are not accidental," Simoncelli says. "We believe that evolution shaped them, and shaped them to be good at what they do. And we have a lot of evidence that that's true."

'Prior' engineering

Whether or not evolution designed Bayesian brains, some of those very brains are now intent on passing their Bayesian abilities on. Trained as an engineer, Simoncelli says that the same principles at work in the brain could be incredibly useful elsewhere. "My belief is that when we finally figure out how some of these circuits operate in brains in order to accomplish these feats, we're going to change engineering," he says. "We're going to revolutionize the way we think about designing systems."

Many of today's robots, for example, excel at precise tasks but are totally inflexible. Robots that install windshields on new cars perform the job flawlessly each and every time. "We can make that robot be fantastically good at putting that windshield on," Simoncelli says. "They're beautifully engineered systems." But those paragons of windshield installation would have a complete meltdown if they were handed a glass sheet of the wrong size. A similar robot based on the human brain, though, might easily adapt to changing circumstances and even file away some priors of its own.

Nerve cells exhibit enormous flexibility. Constantly readjusting to input, interacting with neighbors and changing firing rates can lead to incredible adaptability, a prerequisite for Bayesian learning, Simoncelli says. The more scientists understand about nerve cell function, "the more we find they're not fixed, dedicated devices that operate the same way throughout your lifetime," he says.

Cracking the brain's Bayesian operating system might lead to a new set of engineering principles. "We don't know how to engineer systems that are more flexible, and we don't know how the brain works. And we're going to figure both those things out," Simoncelli says. "And I believe that we're going to do it at the same time." ■

Explore more

- For Alexandre Pouget's papers: www.bcs.rochester.edu/people/alex/

Alien-life hunters focus on moons in outer solar system

By Nadia Drake

The solar system's spotted bully and its ringed sidekick are holding some tantalizing treasures in their gravitational clutches. Circling Jupiter and Saturn are more than a hundred moons, including some of the most promising hosts for extraterrestrial life in the solar system.

But not every one of these moons is an equal opportunity extraterrestrial petri dish. Scientists are now debating which might be best for a life-seeking mission. Their attention is focused on a frozen trio: Titan, Enceladus and Europa.

For centuries, these satellites appeared in the sky as mere points of light. Now, the three moony musketeers have personalities. Enormous Titan is exotic, the home of hydrocarbon lakes and a thick atmosphere. Tiny Enceladus spits salty water into the void around Saturn. And deceptively placid, ice-crusted Europa probably hosts a sloshing ocean so deep it tickles the moon's rocky mantle.

Scientists don't expect to find Europan plesiosaurs or Titanian redwoods, of course. But some experts think these moons may be the best chance for turning up tiny, animated microbes — or at least their footprints.

"It's worth noting that the three strongest candidates are all in the outer solar system," says Alan Stern of the Southwest Research Institute in Boulder, Colo. Indeed, these far-flung worlds might even trump Earth's nearest planetary neighbors. "The inner planets are not such good candidates. Venus, Mercury — not even on the list. Mars? Not as high as these three."

Deciding which of the three worlds to visit isn't exactly spawning a knockdown, drag-out fistfight, but some scientists have their favorites. Such preferences are based on characteristics thought to make a habitat friendly to familiar — or unfamiliar — flavors of life.

"When we search for life beyond Earth, I think there are four things we need to look for," says Chris McKay of NASA's Ames Research Center in Mountain View, Calif. First, he says, is liquid water. "That's always the starting point." Second, organic material, which means carbon-containing compounds. "Water is what life lives in; organic material is what it's made of." Third is nitrogen. "You can think of it as the secret ingredient. You've got to add that to make the

Some scientists rank the Saturnian moon Enceladus as the best place in the solar system to go looking for alien life-forms.

organic material biological. It's probably the most important atom after carbon," McKay says. And last, an energy source. "Something to eat. Sunlight if you live near the surface. Chemical energy if not."

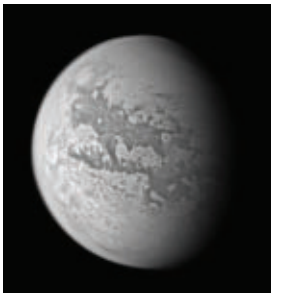
As scientists learn more about how each moon satisfies these requirements, mission preferences are continually reshaped.

"Five years ago, Europa's star was pretty high, Titan's was rising and we barely knew that Enceladus would be important and on this all-star list," remarks Stern, who says he would be surprised if none of these moons hosted alien life. "I don't think it matters which of these three worlds we find it on. Wherever we find life, it will open up a very rich scientific vein."

Moony trio Chris McKay of NASA's Ames Research Center says three outer solar system moons (below, not to scale) are prime candidates for alien life because they fulfill some of the key criteria for habitability: liquid water, organics (aka carbon-containing compounds), nitrogen and an energy source.

- WATER
- ORGANICS
- NITROGEN
- ENERGY

Europa ●
Water is abundant on Europa in the form of an ocean sloshing beneath the icy crust. Scientists don't yet know whether nitrogen or organics are present, but some think hydrothermal vents might erupt from the seafloor and power life.



Titan ●●●
The surface of Titan sits beneath a thick, nitrogen-containing atmosphere and is soaked in organic hydrocarbons, which could serve as an energy source. Whether a water ocean lurks deep underground is not yet known.

Enceladus ●●●●
Water, organics and nitrogen pour into space from the satellite's geysers, which require an energy source for fuel. Still, scientists aren't sure whether liquid water has been around long enough for life to evolve on the tiny moon.

Water wonder

Some scientists think that vein runs beneath Europa's icy crust.

Four centuries ago, in 1610, Galileo Galilei peered through a telescope in Padua, Italy, and spied four moons orbiting Jupiter. Included among them was the water world now known as Europa. At about 3,120 kilometers in diameter, Europa is the runt of the Galilean satellites, slightly smaller than Earth's moon.

Yet this runt has been astrobiology's it-moon since scientists found evidence more than a decade ago for a deep, liquid water ocean underlying its icy surface. Constructed somewhat like a candy cordial with a smooth chocolate outer layer, liquid interior and crunchy core, Europa has a roughly 10-kilometer-thick crust of ice with what scientists believe is a 160-kilometer-deep ocean sloshing beneath.

The ocean probably sweeps up minerals from the moon's mantle, minerals necessary for the building blocks of life to form, says planetary scientist Robert Pappalardo of NASA's Jet Propulsion Laboratory in Pasadena, Calif.

"If we've learned anything about life on Earth, it's that wherever you find water, you find life," says planetary scientist Kevin Hand, also of JPL. "So we follow the water, and Europa is where the water is."

In addition to that salty ocean, scientists suspect that Europa has a tenuous oxygen atmosphere, produced when charged particles from Jupiter's magnetosphere strike the moon's icy surface. Though these processes make the surface inhospitable to life, oxygen could now be saturating the Europan sea and powering life-forms swimming in the abyss, says planetary scientist Richard Greenberg of the University of Arizona in Tucson.

Greenberg recently estimated how long it would take for oxygen to sink through the ice into the Europan soup, once the top few centimeters were saturated. He reported last year in *Astrobiology* that it could be an almost 2-billion-year journey from the surface to the inner salty sea. That time lag following the moon's formation could give aquatic life a chance to develop while shielded from potentially damaging oxygen, just as life on Earth developed free of oxygen for its first billion years.

"Life could get going during those 2 billion years, and it could form protective structures like cells," Greenberg says. Now, it's possible for microorganisms — and even more complex life-forms — to use that oxygen as energy, he says.

Hand thinks simple life-forms are more probable, because sulfur compounds appear to be abundant on Europa and microbial life can exist quite happily on sulfur-based fuel.

Punching through the icy rind to access either type of organism would be a tricky task for an unmanned vehicle of the kind that might visit Europa. But some scientists think that the moon's juicy innards might be spurting through cracks, carrying some signature of life beneath (if not the life itself). The luminous white surface is smeared with dark red, possibly sulfur-rich deposits that could be by-products of microbial metabolism, Pappalardo says.

The surface ice at Borup Fiord Pass, on Ellesmere Island in the Canadian High Arctic, has similar sulfur streaks. In *Geobiology* in July, Pappalardo, JPL's Damhnait Gleeson and colleagues identified a community of microbes living at the deposits, suggesting that the smears are the result of sulfur-oxidizing metabolism by the microbes.

Now, the team is working on identifying markers that would distinguish biological activity from mineral processes that could also produce the discolorations — and thinking about ways to remotely detect such differences, since Europa's harsh conditions mean a spacecraft couldn't stick around there for long.

OPPOSITE PAGE: NASA, JPL, SPACE SCIENCE INSTITUTE; THIS PAGE, FROM LEFT: GALILEO PROJECT, JPL, NASA, REPROCESSED BY TED STRYK; NASA, JPL, SPACE SCIENCE INSTITUTE; NASA, JPL, SPACE SCIENCE INSTITUTE

Otherworldly option

Whether the second criterion for life, organic material, exists on Europa is a big question mark. But another candidate moon, Titan, is soaked in it.

Dutch astronomer Christiaan Huygens glimpsed Titan orbiting Jupiter's ringed neighbor, Saturn, in 1655. As its name implies, Titan is big — roughly 5,150 kilometers in diameter, larger than Earth's moon or the planet Mercury. Images of Titan at first just showed a blurry, orange-blue edge, the fluffy footprint of its thick, nitrogen-rich atmosphere.

It wasn't until the appropriately named Huygens probe descended to Titan's surface in January 2005 that astronomers could directly glimpse the veiled moon's surface. And it kind of looked like home, on a hazy day.

Aside from Earth, Titan is the only body in the solar system known to have stable liquids on its surface, in the form of streams and seas. The landscape looks so similar that some researchers think Titan could be a gold mine for clues about Earth's early history. "We can learn about the evolution of organic chemistry, which is presumably part of the process that led to life on Earth," says planetary scientist Ralph Lorenz of Johns Hopkins University.

Titan's surface lakes are not bodies of water, though. Instead, they're filled with methane and ethane, hydrocarbons that behave differently from water molecules. Normally gases on Earth, these compounds are liquid at Titan's surface temperature of –180° Celsius.

And it rains on Titan. Dense clouds seasonally sprinkle the moon with methane, scientists reported in March in *Science*, raining down upon a surface characterized by modest mountains, dunes resembling asphalt and rocks made of water-ice.

"It's an organic chemist's dream, but not necessarily a biologist's dream," Hand says.

Still, Titan could host its own brand of surface inhabitants based on hydrocarbons, with biochemistries very different from those on Earth. "Titan is where you go if you're looking for weird life," he says.

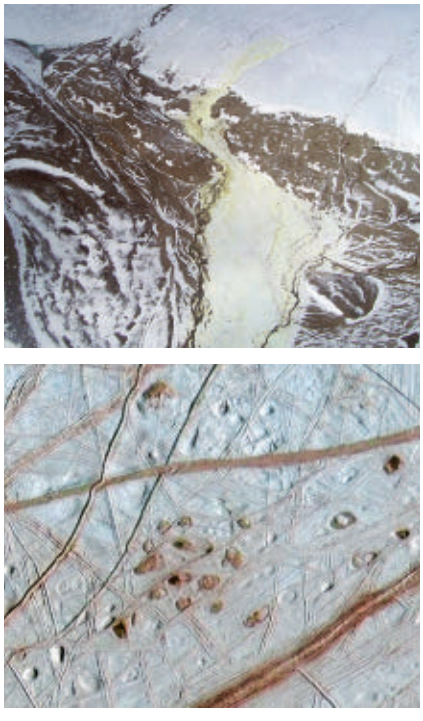
A Titan mission in the planning stages would look for at least the beginnings of any such life. After splashing down in a 100,000-square-kilometer hydrocarbon lake called Ligeia Mare, the Titan Mare Explorer would seek out large, complex assemblages of organic molecules, compounds that might form into single amino acids or proteinlike structures.

Sailing the methane lakes of Titan captures "a little bit of the romanticism of ships exploring Earth's ancient seas," says astrobiologist Dirk Schulze-Makuch of Washington State University in Pullman.

Of the chance of finding life on Titan, "I would say it's probably 50-50," he says.

Scientists don't know enough about how life evolved on Earth to rule out the possibility of a hydrocarbon-based lifeform, though attempting to detect such critters could be a challenge. "We have to be very open-minded and creative here," Schulze-Makuch says. "If life exists, how it looks and how it interacts with the environment, that could all be very different."

While some scientists suggest Titan might host a deep, water ocean with aqueous ammonia tens of kilometers below the crust, such a pocket of liquid can't be sailed and any more-familiar forms of life residing there would be basically inaccessible to any space probes.



Sulfur streaks Red streaks visible on Europa's surface (bottom) may be akin to yellow streaks currently under study in the Canadian High Arctic (top). The Arctic streaks are rich in sulfur and may be produced by a community of microbes living nearby. Scientists are now looking for remote markers of such life.

Superfecta satellite

The salty water reservoir stirring beneath Enceladus' surface, though, is known to shoot samples into the void around Saturn.

In 1789, more than a century after Titan's discovery, Saturn's tiny moon Enceladus first glimmered through William Herschel's lens. But no one realized it was a giant water fountain until the Cassini spacecraft dropped in for a visit, snapping some astonishing pictures.

In 2005, Cassini swung by the Saturnian moon — only 500 kilometers across — and observed plumes of material erupting from its south pole. When Cassini imaging team leader Carolyn Porco first saw the jets, she says, she felt "a strong sense of kinship with those long ago who first set eyes on the geysering turmoil of Yellowstone."

The plumes are enormous geysers spewing icy water and salty particles hundreds of kilometers into space. The moon-spit is loaded with organic material and not only forms one of Saturn's fainter rings, the E ring, but also rains down on the planet. Enceladus is the only moon in the solar system known to influence its planet's chemistry. Its contribution solves the mystery of where the water in Saturn's upper atmosphere comes from, scientists reported in the August 2011 *Astronomy & Astrophysics*.

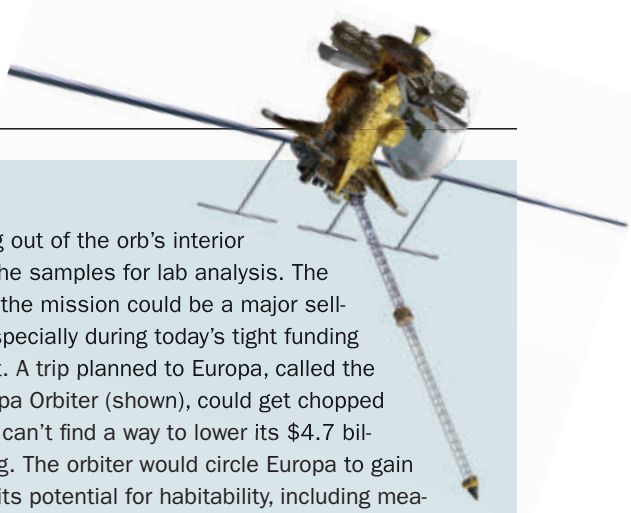
"The plumes are, in my opinion, the most spectacular dynamic phenomenon we've discovered at Saturn, and one with the most profound implications," says Porco, of the Space Science Institute in Boulder, Colo.

Now, scientists think the reservoir beneath Enceladus' icy crust feeds the plumes, as suggested by Frank Postberg of Heidelberg University and colleagues in the June 30 *Nature*. If such a reservoir is the source of the plumes, liquid water must exist beneath the crust.

FROM TOP: D. GLEESON, NASA, JPL; NASA, JPL, UNIV. OF ARIZONA, UNIV. OF COLORADO

Moonbound missions

Scientists have a few proposals for getting up close and personal with any life that may be lurking on an outer solar system moon. The Titan Mare Explorer, in the running with three other Discovery class missions for approval in 2012, would splash down in one of Titan's hydrocarbon lakes and sail the planet's seas to learn more about its chemistry. Another one of Saturn's moons, Enceladus, could be the future destination of a mission aptly named "LIFE" for "Life Investigation For Enceladus." During a flyby costing less than $500 million, the craft would collect samples from jets spewing out of the orb's interior and return the samples for lab analysis. The low price of the mission could be a major selling point, especially during today's tight funding environment. A trip planned to Europa, called the Jupiter Europa Orbiter (shown), could get chopped if scientists can't find a way to lower its $4.7 billion price tag. The orbiter would circle Europa to gain insight into its potential for habitability, including measuring the thickness of its icy crust. — *Elizabeth Quill*



NASA, ESA

Porco says salt concentrations in the plume hint at a reservoir in contact with rock, which means the same kinds of chemical reactions that take place on Earth (and can support life that does not rely on photosynthesis) might be occurring on the moon.

It's also warm, at least zero degrees Celsius: "a balmy place for lots of organisms to thrive," Porco says.

The plumes make the moon's innards relatively easy to study, which is one reason Porco, McKay and many other scientists favor a mission to Enceladus.

"The samples are coming out for free," McKay says. "It's like there's a big sign saying, 'Free samples, take one.'"

Enceladus has water, organics, nitrogen and an energy source — the only place in the solar system with all four boxes checked, McKay says. "If I had a little scooter and could fly anywhere, the first place I would fly is the plume of Enceladus," he says.

A mission to Enceladus could be much more focused than a visit to, say, Europa, Porco says, since scientists know where all the action is. There are at least 70 jets bursting from fractures at the south pole, the most vigorous of which are associated with the hottest locales. A probe could land near the plume and collect the contents as they rain down, she says. "It could be snowing microbes on the south pole."

But understanding of Enceladus' geochemical processes is still young, and some scientists worry that they don't know enough about the moon to send a mission there yet. Pappalardo, who studies Europa, raises the question of how long a subsurface ocean might have existed — whether it's a transient phenomenon or persistent enough to stick around and allow life to evolve under the ice.

While some models suggest a global ocean is unlikely to last long enough for life to develop, a small regional sea might, Porco says. "The only remaining question is: Is prebiotic chemistry, or perhaps even life, stirring beneath the south pole of Enceladus?" she says. "And the only way we'll know the answer to that is by going back to Enceladus, properly equipped to find out."

Making choices

Though scientists are putting together the pieces of these moony puzzles bit by bit, the pictures will be blurry as long as assembly is from afar. So far, researchers know that Europa is probably a water world, but might not have organics, nitrogen or a life-powering energy source. Titan is saturated with organic material and shrouded by nitrogen, but lacks liquid water on its surface. And Enceladus is superpowered, fulfilling all four of McKay's criteria, but its subsurface pocket of water might be too young for life to have evolved.

Because there is still so much to find out, wherever Earth's robotic emissaries arrive next, they will help sate the curiosity of a legion of scientists. There is no bad target.

"Asking me if I think we should send probes to Enceladus or Titan instead of Mars or Europa is like taking a kid to Disneyland and telling them they can only go on one ride," says Nathan Strange, a mission architect at NASA's JPL who has worked on mission design for all three moons. "Why not let us go explore all of these places?"

Charles Elachi, director of JPL, thinks that's possible. "From a technical point of view, they're within our engineering capabilities of the next 10 years," he says. "I don't have a favorite. As a scientist, the ideal is to go to all three of them. But I would add Mars, too."

The limiting factor is funding, he says. Sending large, multibillion-dollar flagship missions to each of the moons, such as a proposed craft called the Jupiter Europa Orbiter, isn't possible under the current funding climate. So if scientists can't send one large mission to each moon, they'll have to decide how else to distribute the work.

Stern suggests planning smaller trips, less than a billion dollars each (the Titan Mare Explorer falls into this cost category) that could begin to form a foundation for future visits.

"You can't think about the exploration of any of these objects as a one-time trip," says Carl Pilcher, director of NASA's Astrobiology Institute in Mountain View, Calif. "Each mission, we develop a deeper understanding that helps us ask better-informed questions. It's kind of like building a cathedral: It takes a hundred years or more, and each generation passes the torch to the next." ■

Explore more

- For more details on outer solar system planets and their moons, visit: solarsystem.nasa.gov/planets

Singled Out

How to study cells, one by one

By Susan Gaidos

Despite being kept in the same lab conditions, these human colon cells make differing amounts of the protein beta-catenin (green) in their nuclei (blue).

CURTIS THORNE AND CHONLARAT ("PEARL") WICHAIDIT

Fly over any baseball stadium when the home-team batter slams a double in the gap with two men on base, and you'll see a crowd of fans rising in unison, arms waving wildly in the air. You'd think you were viewing typical baseball fan behavior.

Witness this scene at ground level, though, and you'll get a different picture. While a majority of fans participate in the cheering, others are sipping beer, attending to scorecards or roaming the walkways in search of a hot dog.

Such displays of individuality shouldn't come as a surprise — people often react differently to the same circumstances, after all. But life's individuality thrives at much smaller scales than the human body.

Cells, for example, are not all alike. Clusters of single cells, even of all the same type, show cell-to-cell differences in appearance, growth and behavior. This holds true for single-celled organisms too. Individuals within a colony of identical bacteria, for instance, will behave in different ways, even under the same conditions.

For decades, scientists were stuck with an aerial view of cell behavior. Experiments carried out on large pools of cells obscured information on the activities and makeup of the individuals. Difficulties in tracking molecules inside a single cell forced researchers to content themselves with averages derived from whole populations.

Now scientists are finding ways to zero in. Improvements in imaging techniques make it possible to view tiny, transparent structures and molecules within cells that are otherwise nearly invisible. New ways of separating cells during study enable scientists to sort through thousands at once, distinguishing subpopulations and studying multiple traits in just one go.

"We used to think that we could take a million cells and grind them up and make measurements on those million cells," says Nancy Allbritton, a biomedical engineer at the University of North

Carolina at Chapel Hill. "And whatever measurements we made on those million cells would reflect what's going on in a single cell."

Scientists today know that averaging the constituents of a million cells often gives no clue to what's going on at the cellular level. Cells thought to be alike have been found to produce different numbers and types of proteins. Beyond providing interesting insights into basic biology, understanding this individuality may have medical consequences — illuminating characteristics that can make a cell more amenable to a particular drug or more vulnerable to an allergen or viral infection.

Though in many ways single-cell analysis is still in its infancy, the field is quickly expanding. Researchers are working to improve technologies and to figure out how to make sense of the data.

Lighting the way

Of the millions of different living things in the world — large and small, plants, animals and microbes — all have in common the fact that they are made of one or more cells. Scientists have been observing cells since the mid-17th century, when Dutch scientist Antony van Leeuwenhoek discovered bacteria and, later, blood cells. Through the years, microscopes and staining methods have allowed researchers to view and describe the basic structures and internal workings of various cell types — understanding how skin cells, for example, differ from cells in the heart or kidneys.

Distinguishing unique features among cells of the same type has proven to be more difficult, because cells are so small. A typical human cell is about one one-hundredth of a millimeter across. Microbes are even smaller. Conventional light microscopes are constrained by a physical law demanding that the size of an object being imaged be no smaller than about half the wavelength of the light used to produce that image. To see anything as small as a molecule within a cell (the scale at which much of the work gets done), some tool other than traditional light microscopy is needed.

Scientists have found ways to get around this blind spot. When molecules and proteins are labeled with fluorescent dyes, the components inside a cell appear as bright colored dots against the background of a cell's gel-like filling. Such advances have allowed researchers to see cellular processes unfolding at nanometer scales. Fluorescent probes have also brought to light the wide variation that exists within a population of seemingly alike members.

When sorting through a population of cloned lung cancer cells loaded up with fluorescent probes, systems biologist Steven Altschuler noticed that each cell carried its own combination of the molecules that send signals between cells.

"It was a surprise to us," says Altschuler, of the University of Texas Southwestern Medical Center at Dallas, who jointly runs a lab with pharmacologist Lani Wu. "It even made us wonder what the definition of a clone was."

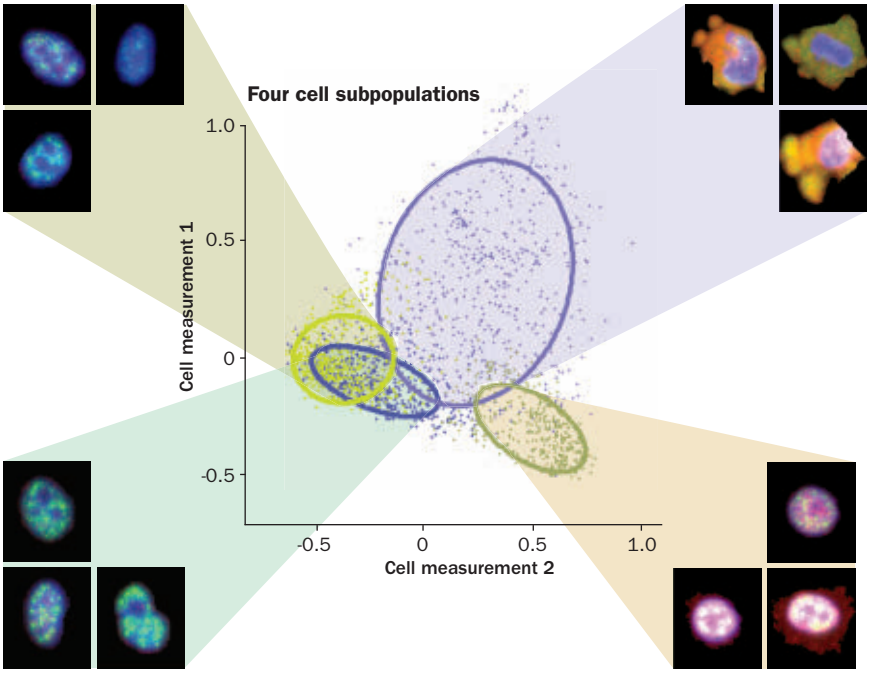
The team developed a way to combine fluorescent microscopy with a type of software designed for face recognition to look for patterns among the cells. The team first labeled the cells by attaching different fluorescent tags to proteins involved in cell signaling. Computers then analyzed pictures of the cells, pixel by pixel, looking for variation in the location and intensity of the molecules. The scientists also trained the computers to identify combinations of markers that commonly appear together — discovering the cellular equivalent of a "blue-eyed blond."

Using this method, the scientists were able to identify small subpopulations of cells, or stereotypes, based on which molecules appeared and where. Exposing the stereotypes to the anticancer drug Taxol revealed that different subpopulations respond differently to the drug. In May 2010 in *Molecular Systems Biology*, the team reported on how individual cell differences could help predict the outcome of treatment.

"That's definitely where we would like to go," Altschuler says. "The dream is that you would be able to look at a small number of cells from a cancer tumor and try to predict the optimal combination of drugs to treat that particular tumor."

Though doctors currently use various profiling techniques to determine

Spotting siblings By combining fluorescent markers and cell-imaging techniques, researchers were able to divide a population of cloned cells into several subpopulations (four shown in chart). Members of each subpopulation showed similar patterns of fluorescence (images).



M.D. SLACK *ET AL*/*PNAS* 2008, ADAPTED BY JANEL KILEY

the best treatment, Altschuler says this new approach differs because, in principle, it would allow a doctor to look at every cell in a tumor biopsy, identifying clues that would get lost in a "population averaging" approach.

Multiplying traits

But fluorescent microscopy has its own limitations. Scientists can look for only a handful of variations, or biomarkers, in a cell at one time. Though cells carrying biomarker A could be distinguished from those carrying B or C, for example, scientists can't simultaneously scan the cells for a second characteristic that might be important in understanding the first.

Altschuler and Wu's team has found ways to maximize the use of fluorescent probes to get more details on cell-to-cell differences. Using three out of four available probes to home in on subpopulations of interest, a fourth probe can be free to search for a second variation within each of those groups. By running a series of experiments, rotating the fourth marker's target each time, scientists can get more detailed information on members in each group.

Say you're trying to understand people at a baseball stadium, instead of cells, and you want to figure out differences in the way the players, vendors and fans dress. Three out of four fluorescent probes would be used to separate people into each of these groups. The fourth probe could then search for a specific item, such as sneakers, which may be worn by members in each group. In subsequent experiments, the first three probes remain set to identify players, vendors and fans, while the fourth spots people sporting home-team jerseys, then baseball caps and so on. A computer program stitches together the information gleaned from the serial studies to show what people in each group wear.

In this process, a scientist will never look at the jerseys and caps on any given person at the game, because only one measurement can be made at once. "Still, reliable information can be gained," Altschuler says. His group is now profiling cells in this way.

At her University of North Carolina lab, Allbritton and colleagues are developing ways to study multiple variables beyond the limitations of microscopy. By employing what they call "separation techniques," the researchers have the potential to measure the activity of many enzymes — a dozen or so — at once. Each cell gets its own well in a grid containing thousands of rows and columns.

Cells are first loaded with various enzyme substrates, substances that work with an enzyme to produce a specific reaction. The cells are then killed and their contents released. By separating out each of the chemicals that were put into the cells as well as the products the cells make, scientists get a readout on what's going on inside.

Because each cell sits in its own well, scientists can analyze the cells separately. Comparing the reactions of different cells is key, Allbritton says, because a study of a single cell won't reveal much variability.

"That's like looking at one human and trying to understand how variable people are," she says. "You would assume if you got a redheaded person that everyone had red hair — and was 5-foot-4 and was female."

Allbritton is using this technique to measure protein activity in human cells. Her studies currently focus on kinases, proteins that play a vital role in cell signaling and the regulation of gene activity.

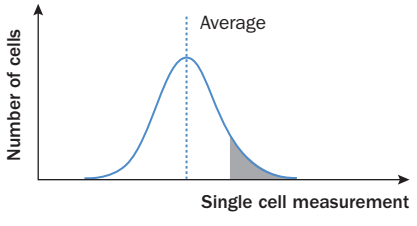
Live on and inform

Such clues to what's going on inside single cells often come at a price: Cells are damaged or killed in the process, providing only a single snapshot in time. This makes it hard to predict how a single cell will respond to a given stimulus.

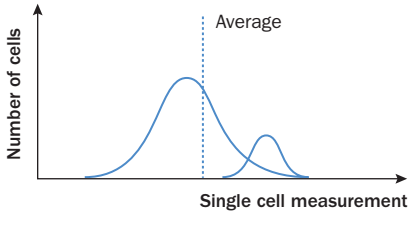
J. Christopher Love, a chemical engineer-turned immunologist at MIT, combines the idea of separating cells and the helpfulness of fluorescent dyes to follow biochemical processes over time in living cells. His lab takes an array of subnanoliter-sized wells and fills each with either a single immune cell or a small group of them. With tens of thousands of wells, the unit looks like an ice cube tray the size of a microscope slide. Fluorescent markers identify the various proteins in or on each cell, distinguishing one cell type from another.

Over the course of several hours or days, Love studies the proteins and chemicals secreted by the cells to see how they change. Borrowing a technique from the printing of U.S. dollar bills, he presses the microarray against a glass plate to get a printout (so to speak) of the proteins and chemicals secreted by the cells. Unlike Allbritton's work, the

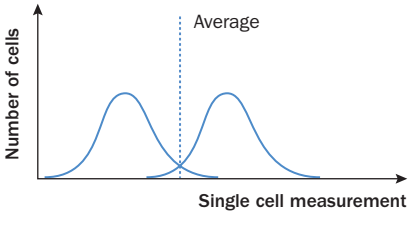
Trouble with averages For a long time scientists had no choice but to study cells by looking at the average behavior of an entire population. Today, many researchers are developing analytical techniques that get around the inherent problems (some below) of this approach.



An average may roughly reflect how most cells behave, but it doesn't capture behaviors that fall far from the center of a bell curve.



Sometimes an average can hide a smaller subpopulation of cells with behaviors that may differ from the larger group.



If the cells are split into two subpopulations, the average may reflect how only a handful of cells actually behave.

S.J. ALTSCHULER AND L.F. WU/*CELL* 2010

method doesn't kill the cells because information is captured from the outside, on the glass plate.

Love is applying this interrogation method to ask questions that are relevant to chronic diseases such as HIV, autoimmunity, cancer and allergies. One ongoing study tracks how allergic patients become desensitized to milk allergens, measuring how the patients' white blood cells respond to milk extracts. The study looks at how many cells are responding, what kinds of immune proteins are being produced and how much of each protein is produced by each cell.

By analyzing large numbers of single events and interactions between small groups of cells in concert, Love can spot rare types of cells and events that are linked to disease. Certain T cells and B cells found in diseases like multiple sclerosis or diabetes, for example, typically are present at rates of 1 in 10,000 to 1 in 100,000 of the circulating T cells in a blood sample, he says. Without looking at many, many cells, he wouldn't be able to spot or study the interactions of these rare types.

"Single-cell analysis is a bit of a misnomer in the sense that you're not really looking at one cell," Love says. "You're resolving to one cell, but you are needing to look at thousands, if not tens or hundreds of thousands, of cells to understand what that individual measurement looks like in relation to the rest of the distribution."

Single microbes

Studies of cell-to-cell differences also promise to reveal new information about single-celled organisms. For a long time, biologists thought that members of a microbe colony were all basically the same, and that those cloned from a single cell, because they were genetically identical, should react to environmental challenges in the very same way.

Scientists now know that individual traits may, in fact, serve as drivers to boost the robustness and resistance of microbial populations, says Michael Konopka, a biochemical engineer at the University of Washington in Seattle. In the October 2010 issue of *Nature Chemical Biology*, he and coauthor Mary Lidstrom outlined how some members of a microbial colony will stop growing in times of stress, moving into a dormant state that allows them to ride out the bad conditions while their neighbors perish.

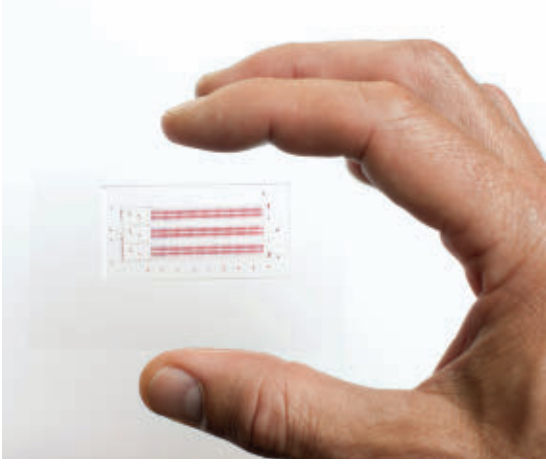
Understanding how individuals adapt to environmental conditions, such as temperature fluctuations, could help engineers find ways to boost certain types of chemical processes used in manufacturing, Konopka says. Some naturally occurring microbes, for example, may have a built-in capacity to do the chemical reactions that industrial researchers want to perform.

Others research teams are developing ways to determine the complete genetic blueprint of single-celled organisms to get insight into whole populations of cells that are otherwise difficult to study. Stanford University scientists working under the direction of Stephen Quake are plucking single cells from populations found in pond scum, soil or even plaque on teeth, to ask a seemingly simple question: Who are you?

Conventional genetic analysis techniques require a large, pure sample of the microbes, says Paul Blainey, a postdoctoral researcher in Quake's lab. "That usually requires that you're able to isolate the particular organism and grow up a whole huge beaker of it in the lab." Unfortunately, the chemical reaction used to amplify tiny amounts of DNA is notoriously prone to contamination.

To get around this problem, the Stanford group is using a laser tweezer to sort individual microbes inside tiny, automated devices designed to analyze minute traces of DNA. Enclosed within this miniature lab, microbes and their DNA are safe from contaminants.

In 2007, Quake's group analyzed the genome of a single bacterium found in dental plaque taken from a person's mouth. This year the team turned to a less familiar class of single-celled organisms, the Archaea: Online February 22 in *PLoS One*, the researchers published findings on the genome of a single-celled ammonia-eater from San Francisco Bay.



UNIV. OF BRITISH COLUMBIA

Developed at the University of British Columbia, this microchip allows the simultaneous analysis of 300 cells.

Genetic information gleaned from an individual microbe, combined with findings on cell-to-cell differences in behavior, may provide new insights into the thousands of unknown or barely known populations found in water and soil. Such insight could in turn offer clues to how microbes act as infectious agents and how they develop resistance to antibiotics.

Despite recent gains in studying single cells and how they differ, there's much work to be done, Allbritton says. Current techniques still allow only a small number — fewer than two dozen — of the thousands of molecular components that float around in cells to be measured at one time.

"It's embarrassing," she says. "We've made a lot of progress, but you can see how far we have to go."

With such a small subset of cellular components under study, scientists' perception of how cells operate may be colored by what they see, she adds. The big push now is to develop ways to measure more of the cell's contents, and see how they change over time and work in relationship to each other.

"If we can see everything," Allbritton says, "it might dramatically change how we view the single cell." ■

Explore more

- Altschuler and Wu lab: www4.utsouthwestern.edu/altschulerwulab

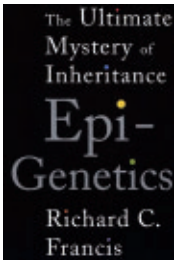
Epigenetics: The Ultimate Mystery of Inheritance

Richard C. Francis

For more than 10 years, scientists have known nearly every letter in the human genetic instruction book. But perhaps more interesting than those letters are the doodles in the margins and the highlighted passages — chemical modifications to DNA and its associated proteins known as epigenetic marks. These scribbles may actually control how genes function, and thus how a person looks and acts. And these changes are passed along to future generations, like carbon copy overlays in new editions.

Researchers are only beginning to decipher this cryptic language, but already it's clear that whatever these graffiti have to say is going to be important. Such epigenetic modification may be at the root of many diseases, for example. Epigenetics links external experiences to the molecular machinery inside cells. Francis' book is intended as a guided tour of this mysterious new landscape.

Each chapter starts with an entertaining or intriguing example of how epigenetics affects human and animal biology and inheritance. It's not often you find José Canseco, mouse mothers, Dutch famine victims, sea urchins, identical twins and Tasmanian devils all in the same book, but you will here. Francis just manages to save his story from crossing into textbook territory by weaving these examples throughout the chapters.



It's still early days for the science of epigenetics, and researchers keep discovering layer after layer of epigenetic wallpaper plastered over DNA. Francis hits the highlights here, but stay tuned for more installments in this fascinating new science. — *Tina Hesman Saey*
W. W. Norton & Co., 2011, 234 p., $25.95

Rambunctious Garden

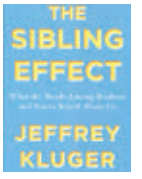
Emma Marris

What does it mean to be wild, and can humans restore wildness to a planet they've spent their history trying to tame? Marris hauls out a wheelbarrowload of research indicating that humans have altered nearly every inch of the terrestrial landscape at one time or another (even ignoring the global transport of air pollutants and perturbation of the climate). So any claim that a place is "pristine," she argues, requires substantial caveats. But Marris makes a strong case that this doesn't mean there aren't ecosystems worth saving, or at least tweaking.

Marris recounts efforts under way across the globe to "rewild" various sites to conditions that existed a century — if not 10 millennia — ago. Such projects invariably require compromises. Once-keystone species may no longer walk or slither across the planet. Budgets may not stretch to do more than a partial job. Unurbanized spaces may be too small to support big carnivores.

If no place is pristine, determining what should be restored ultimately becomes a judgment call. So does determining the benchmarks biologists might use to measure success.

None of these constraints argue for throwing in the towel, or trowel, Marris says. She points to regions where allowing small areas along roads or farms to go untended has brought back species that people had assumed were gone for good. She invites readers to turn the idea of what constitutes smart gardening on its head. One example: Tiny patches of the urban landscape — like yards — could be encouraged (with a little help) to evolve into novel, yet sustainable, marriages of native and not-so-native species. — *Janet Raloff*
Bloomsbury USA, 2011, 210 p., $25

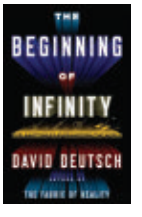


The Sibling Effect
Jeffrey Kluger
A review of recent research shows how siblings affect each other, covering topics such as birth order, blended families and parents who play favorites. *Riverhead Books, 2011, 320 p., $26.95*

Cosmos Close-up
Giles Sparrow
A collection of astronomical images taken by telescopes and spacecraft of all kinds gives brief explanations of the science behind each highlighted object. *Firefly Books, 2011, 320 p., $29.95*

The Exquisite Butterfly Companion
Hazel Davies
This guide to 100 butterfly and moth species comes with a set of butterfly-shaped illustrations to use in craft projects. *Sterling Signature, 2011, 88 p., $14.95*

Brain Bugs
Dean Buonomano
A neuroscientist gives an entertaining look into the brain's hardware and software flaws and how they affect everyday life. *W.W. Norton & Co., 2011, 310 p., $25.95*



The Beginning of Infinity
David Deutsch
A physicist explores the elaborate relationship between science and other realms of human endeavor, with a focus on physical, biological and social phenomena. *Viking, 2011, 487 p., $30*

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Lowdown on Earth's heat

"Science Stats" (*SN: 8/27/11, p. 4*) understates the power Earth radiates into space and mistakenly suggests that Earth radiates more energy from internal sources than it receives from the sun. The total (44 trillion watts) shown in your diagram must represent only the minuscule percentage (about 0.02 percent) from internal energy sources (radioactivity, tidal, remnant gravitational energy) that cause surface effects like volcanoes and plate tectonics. In fact, Earth receives about 174,000 terawatts from the sun and radiates the same amount. Strictly speaking, Earth doesn't radiate any "heat." Instead, it emits energy in the form of light, predominantly at infrared wavelengths because of its modest temperature.
Don McCarthy, Tucson, Ariz.

The reader is correct. The diagram presents heat flow only from Earth's internal energy sources. —Camille M. Carlisle

Zapped on units

The article "Dolphin can sense electric fields" (*SN: 8/27/11, p. 12*) contains an error in the sentence, "Paco could perceive a current as weak as 4.6 microvolts per centimeter...." Current is measured in amperes, whereas electric field is measured in volts per meter.
Robert P. Yassanye, Sarasota, Fla.

The reader is correct. Paco perceived an electric field, as the reported units indicate, not current. —Nadia Drake

Correction

In "Tumor tell-all" (*SN: 9/24/11, p. 18*), a diagram on Page 21 incorrectly omitted coloring showing a segment of chromosome 15 that remained after another part of the chromosome had been deleted. See the correct version online at http://bit.ly/SNTumor

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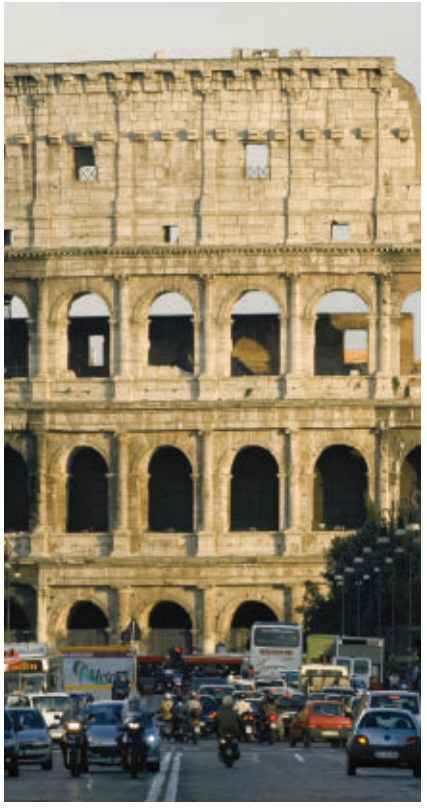

Many of Rome's famous sites sit within the city's Limited Traffic Zone, where motor vehicle access is restricted.

Ancient Rome forbade downtown traffic in day

Ancient Rome had its traffic problems, too, and used some of the same techniques being tried in our big cities today to solve their problems.

Rome's narrow streets were not marked "One Way" but in effect they were, because each driver sent a runner ahead to hold up traffic at the other end of the street or alley until the chariot had passed through.

The fringe parking plan used in modern large cities to relieve the downtown parking problem was used in Rome in the days of Julius Caesar. In the Roman day there were 12 hours of "daylight" adjusted according to the season. Private vehicles were forbidden on the city streets from dawn until two hours before dark. A traveler coming to Rome had to park his carriage at the city gates and continue into town either on foot or in a carrying chair or litter.

Traffic officers in ancient Rome belonged to a corps originally organized to guard against fires. They were officially known as Vigiles, but popularly called the "little bucket fellows." Most traffic restrictions and regulations were lifted at sundown, but the Vigiles handled the situation when two wagon drivers would get into a noisy dispute about the right of way. The police-firemen in Rome were freed slaves, Kenneth D. Matthews Jr., of the University of Pennsylvania's Museum, reports in *Expedition*, 2:22, 1960.

Women drivers were not a problem in ancient Rome. In the third century B.C. a law was passed forbidding women to ride in carriages. Twenty years later the ladies of Rome forced the repeal of this law but during the first century A.D. the restriction was again in force.

UPDATE

Congestion in ancient city isn't a thing of the past

Just because all roads lead to Rome doesn't mean you can get in — at least not on wheels. During Julius Caesar's reign, daytime access to the Eternal City was restricted, with travelers required to hitch their carriages outside the city gates. And, as it turns out, traffic troubles are as enduring as the city itself.

While officials today don't have a problem with female drivers, there is a renewed interest in curbing congestion (and the more modern problem of exhaust fumes). During the 1980s, the city instituted a series of policies that culminated in what's called a Limited Traffic Zone, which keeps all automobiles without special permits or privileges out of a 4.2-square-kilometer portion of the city during much of the day. Motorbikes are excepted, which probably explains why they are commonly spotted zipping past quaint piazzas and historic ruins. Additional measures farther from the city's core try to discourage people from driving extra-dirty polluters and encourage reliance on public transport.

Rome isn't alone in its efforts to relieve traffic woes. A number of cities around the world are experimenting with gridlock busters: Stockholm has plans to finish a ring road designed to divert heavy flow around the city. London charges a daily fee for vehicles that enter a restricted traffic area, a scheme known as congestion taxing. Cologne is targeting its existing transport system, widening roads and improving tram networks.

Though no one will deny Rome's road-building legacy, the next great city may be the one whose roads (and other transport arteries) master the morning commute. — *Elizabeth Quill*

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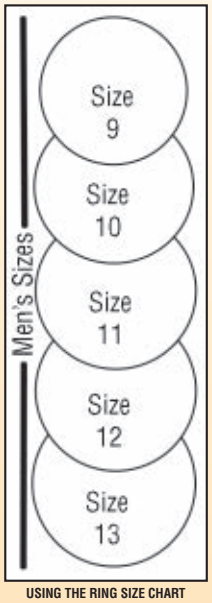

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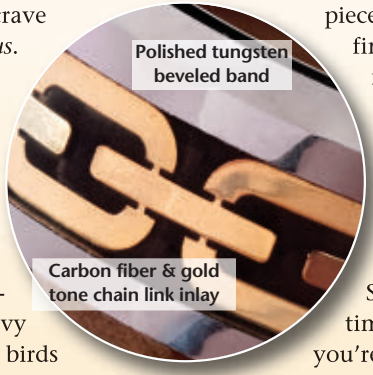

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