SPECIAL ISSUE OUR 2062 WORLD ALMANAC

DISCOVER®

Science, Technology, and The Future

THE END OF YOUTH

An aging world is challenging medical science—and turning society upside down.

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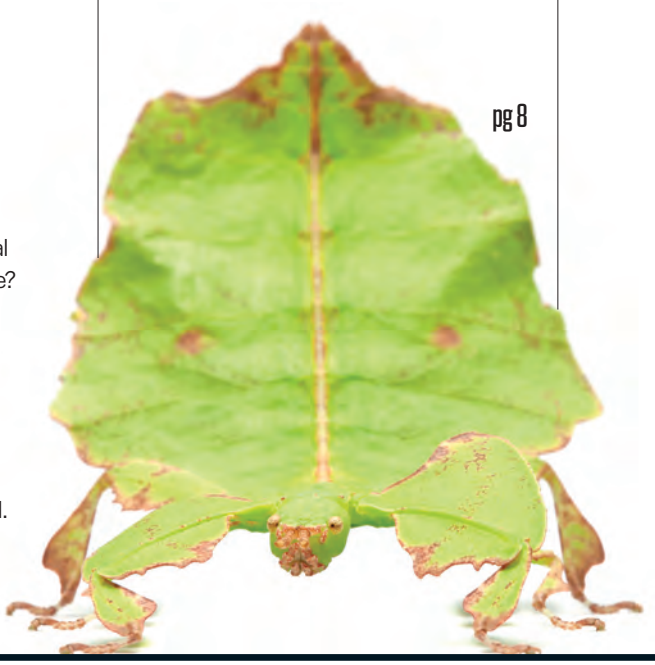

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COURTESY LIBERTY SCIENCE CENTER; MICHEL GUNTHER/BIOSPHOTO; EVERETT COLLECTION

"If we're running out of oil, that also means that we're running out of oil-based plastic. Landfills will turn into gold mines. The easiest way to get the material will eventually be to dig up trash and reuse it."

Debbie Chachra, materials scientist, Franklin W. Olin College of Engineering

The Crux **discovermagazine.com/web/plastic**

Graphene Can Repair Itself
discovermagazine.com/web/graphene

Plants Use Fungi to Digest Insects by Proxy
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The Galaxy That Shouldn't Be There
discovermagazine.com/web/galaxy

July/August 2012

Invisible Intrigue

Chromatic Wonders

Many people are familiar with color blindness, but DISCOVER staff writer Veronique Greenwood introduced readers to a woman who can see millions more colors than the rest of us ("Super Human Vision," page 29). Neuroscientist Gabriele Jordan believes there are many more of these so-called tetrachromats.

I have a very strong suspicion that I am a tetrachromat. As an artist and designer, I've always been frustrated by the insufficient number of colors available in fabric and paint stores. **Diane Powell, M.D.**
Medford, OR

Greenwood responds: *We received hundreds of letters from readers who wondered if they or someone they knew might be a tetrachromat. At the moment there is no way to take Jordan's test for tetrachromacy outside her U.K. lab, nor is there a scientifically rigorous test online. If testing in the United States becomes possible, we will cover it at* discovermagazine.com

Body Swap Skepticism

"5 Ways to Leave Your Body" (page 50) described technology that makes people feel as if they have swapped bodies.

What the scientists in the article call out-of-body experiences may actually be empathy responses. Our brains can make us grab our own arm when a kid falls out of a tree and cry when friends tell painful stories about their lives. We basically inhabit other people's bodies and suffer with them for a short time. I wonder if these experiments could lead to treatments for people who have little or no empathy, like sociopaths.

Lori Shields
Salt Lake City, UT

Canine Intelligence

Behaviorist Stanley Coren's analysis of dog psychology ("Inner Lives of Dogs," page 66) inspired many letters questioning the neural capabilities of man's best friend.

Coren rightly points out that dogs do not feel "higher" emotions such as shame and guilt, despite many owners who would say otherwise. We cannot understand what guilt means without a recognition that we have failed in some way to hold ourselves to a higher standard. For all their intelligence, dogs do not appear to have this conception of moral good. A more interesting question is whether nonhuman primates like gorillas do have the capacity for moral evaluation.

Geoffrey Frasz
Las Vegas, NV

Pillow Invaders

"Mapping the Home's Microbe Habitats" (page 37) described the Wildlife of Our Homes project, led by ecologist Rob Dunn, which is identifying the microbial ecosystems that flourish in U.S. households. Among other findings, the survey has found that many bacteria on toilets match those on pillowcases.

I was amazed by your story about microbes in the home. Can you imagine what there might be in a restaurant?

Fred Kuch
Las Vegas, NV

You can't just leave us hanging: How does fecal matter get on pillowcases? **Norma Frank**
Bryn Mawr, PA

Dunn responds: *We have heard that a relatively high frequency of nakedness goes on in bedrooms, so pillows likely bear witness to a great number of opportunities for the spread of microbes. We have never tried to determine whether the pillows of those who are never naked under their sheets are less like toilets. It just didn't seem polite to ask.*

Finding Alien Urbanites

Traditionally, alien hunters have used radio dishes to try to intercept the interstellar communications of ET. Steve Nadis (Out There, page 88) described a different approach: searching for city lights on other worlds.

Despite the cleverness of this detection method, it is likely that cities built by aliens with intelligence superior to our own will have eliminated light pollution, thus rendering their cities invisible. **Ian Stirling**
Long Valley, NJ

Erratum

In "Hidden Truths of Health" (page 60), we incorrectly stated the year that the drug Vioxx was pulled off the market. It was 2004.

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Population's Peak

WHAT ABOUT OVERPOPULATION?

It's an inevitable question. Conventional wisdom says that the demands of an ever-growing number of humans will soon push our planet's resources to the limit. Surely any discussion of "the future of population" would have to focus there. But two pieces of information steered me—and this issue—in a different direction.

BILL CRAMER/WONDERFUL MACHINE INC

One is the history of failed projections about the consequences of population growth. The most notorious warning came from English economist Thomas Malthus, who in 1798 wrote: "Population, when unchecked, increased in a geometrical ratio, and subsistence for man in an arithmetical ratio." In other words, mouths multiply more quickly than our ability to feed them—yet we are still feeding them. In his 1968 best seller, *The Population Bomb*, biologist Paul Ehrlich more specifically declared, "In the 1970s and 1980s, hundreds of millions of people will starve to death in spite of any crash programs embarked upon now." Famines on that scale never arrived.

Mass starvation is even less likely today than it was in the 1960s.

Second and more important is *why* Malthus and Ehrlich were so wrong. Resources are not fixed things. Better farming can drastically increase the food supply. New energy sources enable much higher standards of living. And then behavior changes in response: More access to resources tends to make people have fewer children, not more. As a result the world's population will probably hit its peak around 2100, followed by a historic leveling off and likely downturn (see page 30).

Those changes will have their own disruptive effects. We will see an overall aging of the world that could slow economic growth and fray the social nets that support the elderly (page 32). We will see more of the afflictions of old age (page 48) and greater efforts to eliminate aging entirely (page 60). Today's inequalities and environmental challenges will not go away, and may yet reach crisis levels (page 52).

But mass starvation is even less likely today than it was in Ehrlich's heyday. Human ingenuity and behavior, not gross numbers, are the real secret to understanding where our species is headed.

Corey S. Powell, EDITOR IN CHIEF

DATA

HEAVENS IN MOTION

Earth and the stars project blurred arcs of motion in this 15-minute time-lapse photograph taken from the International Space Station in March. From 240 miles above Earth's surface, lightning is visible as bright blotches, and city lights appear as yellow streaks; the atmosphere glows in bands of yellow, green, and red as energetic air molecules interact and emit light, a process (called airglow) that is difficult to see from the ground. The circular star trails result from the long exposure as the station, partially visible at top, orbits Earth at 18,000 miles per hour. Astronaut Don Pettit created this photo by remotely snapping 18 shots from an external camera and combining them with imaging software. FANGFEI SHEN

NASA

PORTRAIT OF AN IMPOSTOR

***Phyllium giganteum*, one of the largest of the world's 30 or so species of leaflike insects, peers at the camera in photographer Michel Gunther's Paris studio. Indigenous to Malaysia, this 4-inch "walking leaf" matches the shape and blotches of the plants it eats. Its organs are gathered in a small ridge on its underside to allow a slender, leafy physique. The insect's breezy swaying completes its camouflage. Although females like this one can reproduce by cloning themselves, they also mate with males to enable genetic exchange and promote diversity—driving the evolutionary engine that allowed the insects to blend in with their environment in the first place.** EMMA BRYCE

MICHEL GUNTHER/BIOSPHOTO

BIG idea

TAP THE HEALING POWER OF POOP

For patients chronically debilitated by colitis, transplanting feces from a healthy donor can offer a lifelong cure.

It's flushed down dark pipes into malodorous sewers. It is the very definition of "waste." But it turns out that human feces may also have amazing healing properties, due to the trillions of colon microorganisms that it contains. Stool from a healthy person, recent findings show, can cure nine out of ten chronic cases of potentially deadly colitis caused by the intestinal bacterium *Clostridium difficile*. Moreover, healthy stool might treat a range of other disorders, from Crohn's disease to constipation.

The procedure of transferring stool to a patient—technically called fecal microbiota transplantation—was first performed in the United States in 1958 to treat an intractable case of *C. difficile* colitis, a gastrointestinal condition caused when the balance of microbes in the gut—called the microbiome—is destabilized or destroyed. The goal was to banish *C. difficile* by overpowering it with healthy microbes so that balance could be restored. The experiment worked, and last year a review of 317 patients treated by 27 different research groups found an astounding 92 percent cure rate from this unusual therapy.

Now a group of physicians have designed the fecal treatment's first double-blind trial, in which neither patient nor researcher knows whether a placebo or a healthy microbiome is being delivered to the ailing gut. Before that can happen, though, the FDA needs to approve the use of healthy donor stool as an "investigational new drug." Then the National Institutes

of Health must provide funding.

Colleen Kelly, a gastroenterologist in Providence, Rhode Island, who is helping design the trial, says the first patient she treated with a fecal transplant was a premed student in 2008 who was completely debilitated by six painful months of *C. difficile* colitis. "I tried every standard regimen of treatment. Nothing worked," Kelly says. After the patient received a transplant of her live-in boyfriend's stool, she was cured. "When I saw her at follow-up, she looked fantastic," Kelly says, "smiling and completely symptom free. She told me she'd felt better the same day as the transplant. I've done 72 of these now, and I hear that again and again."

Growing interest in the unconventional therapy is due in part to the fact that *C. difficile* colitis cases have tripled in the past decade and now afflict more than half a million people a year. "*C. difficile* colitis is a terrible problem, and fecal transplant results are astounding," says Lawrence J. Brandt, emeritus chief of gastroenterology at Montefiore Medical Center in New York. He is a proponent of fecal transplant therapy as a primary treatment for *C. difficile*, rather than as a last resort.

A CRISIS OF COLITIS

The need for a better treatment is great. *C. difficile* occurs mostly in hospitalized patients who have received antibiotics, which kill off many of our "good" bacteria. Up to 20 percent of infected patients suffer at least one recurrence; 35 percent of those go on to have a second; and 65 percent of those are likely to have even more. A few sufferers actually have their infected colon removed in order to "cure" the disease.

Alarmingly, a decade ago a virulent strain emerged that can attack individuals after just one routine course of antibiotics. The new strain produces up to 23 times as much of the disease's primary toxins as the common version. Like most strains of *C. difficile*, it also produces heat-resistant spores that can persist and lead to relapse.

In 2010 gastroenterologist and immunologist Alex Khoruts of the University of Minnesota analyzed the microbiome of a 61-year-old woman suffering from recurrent *C. difficile* colitis so severe that she was in a wheelchair with diapers. Prior to receiving donor stool from her husband, her microbiota were largely pathogenic, as indicated by DNA sequencing. Two weeks after a fecal transplant, her flora resembled that of her husband. She recovered completely.

THE FECAL TRANSPLANT

At present, fecal transplantation is a simple protocol. A donor (often a healthy relative or close friend) is tested to be sure he or she doesn't carry any of the common blood or gut diseases, while the recipient undergoes the same kind of cleansing prep one would get before a colonoscopy. Then the doctor processes the donated feces into a smooth liquid consistency and infuses it into the patient's colon via a colonoscope tube or enema. The healthy microbe community in the sample then begins to take over and populate the patient's gut, restoring a balanced microbiome.

Despite strong anecdotal and case evidence, only a few physicians scattered around the country actually perform fecal therapy. It won't be more widely used until we have the technology to analyze a microbiome precisely in a clinical setting, and until that planned double-blind study takes place. Advances in DNA analysis may also identify the specific elements in the donor feces that set the system right.

For Kelly, the future cannot come soon enough. "We are looking at this as akin to a tissue or organ transplant," she says. "A healthy gut microbiome functions like an organ, and it's something you can't live without. We're transplanting a healthy microbiome. We do the fecal transplant and we're giving them something back that has been missing. These bugs have an effect on energy and immune function in a dramatic and mysterious way," she says.

And *C. difficile* colitis is just the start. An Australian pioneer in fecal transplants, Thomas Borody, has performed the procedure in more than 1,900 patients, and has also found success treating irritable bowel syndrome, profound constipation, and otherwise intractable Crohn's disease. "Crohn's will often slowly regress with repeated fecal infusions," Borody says. With typical Australian humor, he concludes, "It's a whole new form of therapootics." JILL NEIMARK

A USER'S GUIDE TO YOUR MICROBIOME

Trillions of microbes inhabit the human body, protecting us from pathogens and keeping our systems in tune. Now scientists at the Human Microbiome Project, funded by the National Institutes of Health, have sequenced the genomes of almost every strain we harbor and mapped them to the organs where they live. Researchers worldwide are discovering the specific roles microbes play in our health. AMY BARTH

NOSE **People with chronic rhinosinusitis—a sinus inflammation responsible for about 22 million U.S. doctor visits a year—have significantly less bacterial diversity in their noses than healthy controls. They also have an excess of normally innocuous *Corynebacterium*.**

LUNGS **Newborns with certain types of bacteria in their lungs are more likely to develop asthma. A study in adults suggests asthmatics have far more bacterial diversity in their lungs than those without the disease.**

REPRODUCTIVE SYSTEM **In June obstetricians described the vaginal microbiome of pregnant women. By the third trimester, *Lactobacillus johnsonii*, usually found in the gut to help digest milk, becomes abundant, presumably to prepare infants for digesting breast milk.**

FROM TOP: ISTOCK; MARK WIENER/ALAMY. OPPOSITE: FRANCK ALLAIS/GALLERY STOCK

COSMIC CLUES

The Z Machine, shown here in a painting.

A Dying Star Is Reborn in a Lab

ASTRONOMER DON WINGET STUDIES STARS, YET HIS TARGETS are never more than yards away. For the past two years, Winget and his colleagues at the University of Texas at Austin and Sandia National Laboratory in Albuquerque, New Mexico, have been creating searing plasmas that are, in effect, miniature versions of white dwarfs, ancient stars that have burned up all their nuclear fuel. "Astronomy has now become an experimental science," Winget says.

White dwarfs are the slowly dying embers of stars like our sun. With no nuclear fusion to sustain them, they collapse into Earth-size balls of tightly bound carbon and oxygen nuclei with an outer layer of hydrogen plasma (disrupted atoms). Astronomers have a lot to learn about white dwarfs, starting with the stars' plasma exterior, since that is the only part directly visible through a telescope.

So in 2010 Winget decided to try fabricating the plasma himself. He took a cigar-size sample of hydrogen gas and exposed it to blasts of electricity from Sandia's Z Machine, which generates more powerful electrical pulses than any other man-made tool. Within 20 billionths of a second, 26 million amps of current transmuted the room-temperature hydrogen into 20,000-degree-Fahrenheit plasma, similar to that observed on the surface of white dwarfs.

Now that Winget has performed more than 30 simulations, astronomers can start using his measurements of how hydrogen plasmas absorb and emit light in the lab to make sense of actual white dwarfs. The new data should help scientists calculate the ages of these fading stars and gain insight into how matter behaves under extreme temperature and pressure. JOSEPH A. BERNSTEIN

CLOCKWISE FROM TOP LEFT: COURTESY LEAH FLIPPEN/DON WINGET/THE UNIVERSITY OF TEXAS; PLANETARY VISIONS LTD/PHOTO RESEARCHERS; COURTESY MARS CHOCOLATE NA; COURTESY HERITAGE AUCTIONS; AP PHOTO/SCP AUCTIONS; COURTESY SOTHEBY'S; COURTESY TARISIO; SETH JOEL/CORBIS

CONNECTIONS

Science on the Auction Block

In May, Edvard Munch's 1895 pastel artwork *The Scream* sold for $119.9 million, the highest price ever paid for art at auction. Weeks later a 70 million-year-old, 24-foot skeleton of *Tyrannosaurus bataar*—a cousin of the *T. rex*—received a bid of $1.05 million at auction. Here, we show how science rarities (and some other famous objects) fared on the block. FANGFEI SHEN

Codex Leicester, scientific writings by Leonardo da Vinci
$30.8 million

The Birds of America, first edition book by John James Audubon
$11.5 million

SCIENCE

VS. THE REST

The Scream, artwork
$119.9 million

Stradivarius violin
$15.9 million

Babe Ruth jersey, circa 1920
$4.4 million

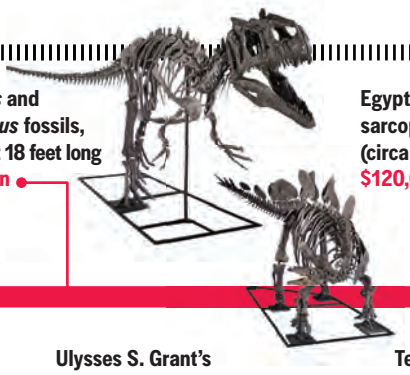
Did Refugee Women Found Madagascar?

A.D. 830: A storm sends an Indonesian trading ship drastically off course. Months later, dozens of ragged survivors make landfall on an island off the southeast coast of Africa, more than 3,000 miles from home. Today, Murray Cox, a computational biologist at New Zealand's Massey University, says a scenario like this may describe the murky origins of the first permanent settlements on Madagascar, home to about 22 million people today.

Genetic and linguistic studies suggest the island's native Malagasy people are mainly of Indonesian descent. The idea of early Indonesians traveling 3,000 miles to the island intrigued Cox. "It's a surprisingly long distance to come," he says. So he used computer modeling to parse the clues, running through 40 million settlement simulations. Cox soon pinpointed one that would explain the DNA patterns evident in Madagascar today. Surprisingly, the current population descends primarily from just 30 or so Indonesian women who arrived 12 centuries ago. His conclusion is supported by prior findings that about 30 percent of Malagasy have the same mitochondrial DNA, which is passed from mother to child—far less diversity than in typical human populations, which share less than 2 percent. "This suggests rapid, recent growth from a very small founder population," Cox says.

It is unclear how Madagascar's founding mothers (and the fathers who must have been with them) arrived. Cox proposes seafaring merchants thrown off course, or refugees fleeing political strife; the latter could explain why women, usually not found on trade ships, were on board. Now, Cox plans to explore whether small founding groups are characteristic of other early island settlements, including Hawaii. "There may be general rules for settling islands," he says. JENNIFER ABBASI

An epic medieval sea journey brought settlers to Madagascar.



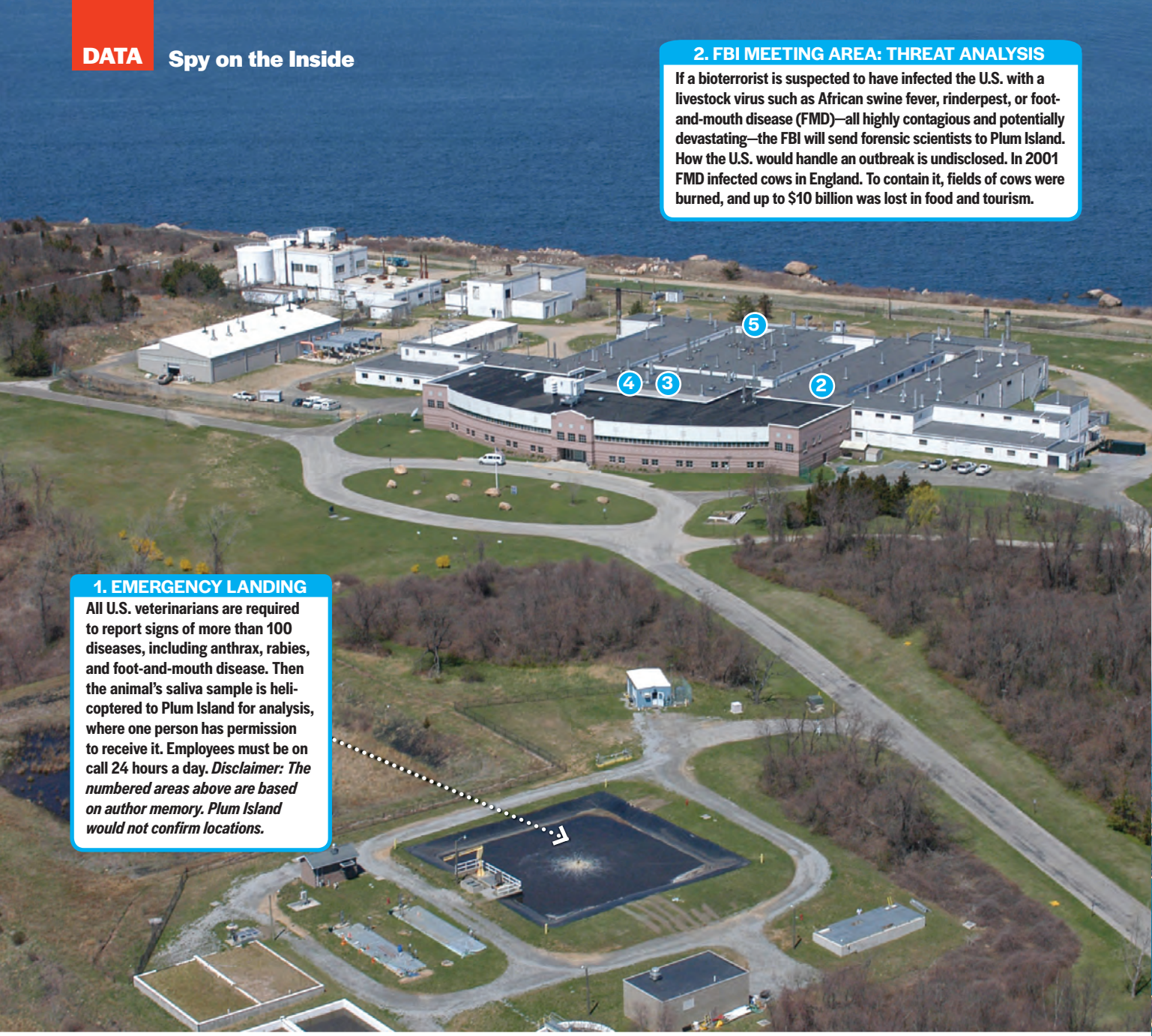
***Allosaurus* and *Stegosaurus* fossils, each about 18 feet long**
$2.7 million

Egyptian sarcophagus (circa 1000 B.C.)
$120,000

Single brown M&M flown on SpaceShipOne
$1,400

Ulysses S. Grant's sword
$1.7 million

Teenage Mutant Ninja Turtles, early drawing
$72,000



PLUM ISLAND

We look inside the lab that studies some of the world's most threatening pathogens.

Fernando Torres-Vélez waits for samples in the darkness by a helicopter landing pad on Plum Island. Situated 1.5 miles from the eastern tip of Long Island, the island's 840 acres of wildlife surround a handful of high-security laboratories run by the Department of Homeland Security to combat livestock diseases and bioterror threats.

Torres-Vélez, a veterinary pathologist, takes a ferry here five days a week as head of the Foreign Animal Disease Diagnostic Lab. But tonight is different. A veterinarian at the New York State Fair has reported a cow with symptoms of foot-and-mouth disease (FMD)—a virus that leaves livestock covered with lesions, too emaciated to produce milk or meat, and so contagious that an outbreak would halt all dairy and beef production in the U.S. When the helicopter lands, Torres-Vélez receives the cow's saliva sample and rushes to his lab. Within four hours his team has ruled out FMD.

Plum Island is a biosafety level 3 lab, equipped to deal with diseases that don't infect humans but are contagious and possibly fatal in animals. Vaccines developed here could stop viral outbreaks in the U.S., as well as in India, Pakistan, and Afghanistan—nations where FMD still poses a threat.

Given the stakes and the intrigue, Plum Island has gained a reputation for being secretive and covert. That may be deserved. A recent visitor found scientists eager to discuss their work yet careful to abide by public relations rules not to say too much. Photography was restricted unless an escort directed the camera. (Verboten: photographing the ferry dock from the Long Island side.) And yet soon Plum Island may be superseded. Within a decade, the lab is expected to move to a brand-new biosafety level 4 facility in Kansas, where scientists can study Nipah virus encephalitis and other livestock diseases that could be fatal to humans. Plans for the facility are stacked on Torres-Vélez's desk. AMY BARTH

ALL IMAGES: COURTESY U.S. DEPARTMENT OF HOMELAND SECURITY/PLUM ISLAND

3. DECONTAMINATION ROOM

Entering or exiting a biosafety level 3 facility like Plum Island's livestock lab requires following strict protocol. The exit procedure: Place used clothing in hampers; blow your nose in a tissue; clear your throat and expectorate to remove mucus, which may contain particles inhaled in a lab; place glasses in the decontaminating solution for three minutes; take a full-body shower.

4. MEN'S EXIT SHOWER

Men shower here after leaving the biosafety level 3 area and the animal labs. The shower rinses off live virus particles that could infect livestock back home. When working in these areas, employees leave their civilian clothes behind, donning full lab attire that exposes only their face, neck, hair, and hands.

Plum Island is accessible by government-authorized ferry.

5. LIVESTOCK LAB

Pigs, sheep, and cows take part in experiments to cure disease. A recent Plum Island accomplishment: the first molecular vaccine for foot-and-mouth disease, approved for use in U.S. cattle this June.

LAB 257 AND THE RUMOR MILL

Lab 257 is an abandoned building across the island from the current center. It was intended to house biowarfare research by the Army, but the project was canceled in 1952. Instead, the government studied animal diseases there before mothballing the building in 1995. Its mystery and inaccessibility have sparked many rumors.

***Rumor*: West Nile virus** was released by Plum Island before the 1999 outbreak on the East Coast—the first appearance of the deadly illness in the U.S. The lab denies this but says it assisted after an outbreak of West Nile in horses on Long Island. Researchers collected samples and aided in development of an equine vaccine.

***Rumor*: Lyme disease** originated on Plum Island during bioterrorism research. Plum Island officials say Lyme disease has never been studied there.

***Rumor*: Grotesque creatures** were created by Plum Island researchers. The lab says its research is unclassified, and no such entities have been created.

THE CONTRARIAN: Derek Lowe

America Does Not Have a Scientist Shortage

CONVENTIONAL WISDOM: A lack of young scientists and engineers threatens our nation's competitiveness.

THE CONTRARY VIEW: We need to worry about the quality, not the quantity, of U.S. scientists.

The U.S. should value ingenuity and creativity over the number of scientists entering the workforce.

SINCE THE SOVIETS' LAUNCH of Sputnik in 1957, Americans have suffered from a recurring fear of falling behind in science. Now, with the economy sputtering and the rise of foreign powers like China, that fear has resurfaced.

To address those worries, many people are embracing a familiar and seemingly logical solution: Get more Americans to become scientists and engineers. Politicians, the media, even the nongovernmental National Academies have parroted the view that the country is facing a critical shortage of scientists and that training more of them will result in increased innovation.

In reality, the United States has been producing plenty of scientists. Enrollment in graduate science and engineering programs increased 35 percent from 2000 to 2010, according to the National Science Foundation. Yet simply having more science graduates does not magically translate into innovation. Many of these young scientists are getting stacked up in career holding patterns, spending years (even decades) in postdoctoral positions while looking for jobs that are not readily available. To pick one hard-hit field, the unemployment rate for chemists and materials scientists almost doubled from 2010 to 2011, to 6.1 percent.

Compounding the problem, many science and engineering jobs are going overseas. The fine-chemical industry, which produces complex compounds for pharmaceuticals and other advanced applications, pays domestic scientists about $55,000 annually, on average. It can pay a chemist in India $6,000. American employees can be more productive and capable than their international counterparts—but not necessarily by enough of a margin to justify salaries nine times as high.

The lesson here is that we cannot just shepherd Americans through science education and expect a slew of new medicines, space missions, and energy solutions. Instead of churning out more scientists, we need to groom better ones. We need to identify the best students and expose them early to real research so that they choose a career pursuing discoveries rather than working on Wall Street. Then we need to spur on these young innovators with competitions and media recognition. We are on the right track with big-money contests like the X Prize, but we should also offer competitive funding for small but significant discoveries. Developing a new chemical reaction may not warrant a Nobel Prize, but it might make a major difference for a wide range of industries, from pharmaceuticals to solar panels.

Discovery is a unique currency. The United States will not improve its scientific standing unless it fosters ideas and inspiration.

Daunting Stats for Aspiring Scientists

633,000: Graduate students in science, engineering, and health fields in 2010. Less than a quarter secure a tenure-track academic job within five years of earning a Ph.D.

63,000: Postdoctoral appointees in science, engineering, and health fields in 2010, up 45 percent from 2000. Many of these postdocs cannot find permanent employment.

3: Percentage decrease, from 2006 to 2011, in federal funding for nondefense research and development, which is a major driver of science-related jobs.

Derek Lowe is a medicinal chemist who blogs at In the Pipeline (**pipeline.corante.com**).

Microbes From the Dinosaur Age

Hans Røy opens a core of sediment hauled up from the seafloor.

Hans Røy expected few surprises from the chunk of reddish mud his team had just hauled from the bottom of the Pacific Ocean. Røy, in the midst of a month-and-a-half-long nautical expedition, simply wanted to study the chemistry of the seafloor and determine how much oxygen it absorbs from the water above.

But after comparing predicted levels of oxygen to the new measurements, the geomicrobiologist from Aarhus University in Denmark realized that some of the expected oxygen was missing. His hunch: A hidden population of microbes was living in the mud, breathing in the oxygen.

To investigate the theory, he examined the bottommost layers of the muddy sediment. In those deep layers, Røy found about 10,000 single-celled microbes per cubic inch, alive and breathing—but only barely. The microbes metabolize oxygen at a rate one two-millionth that of cells in the human body, giving them one of the slowest metabolic rates of any organism known. "They are hanging on in a state of sustained starvation," Røy says.

The deep layers Røy examined have been undisturbed for 86 million years, meaning that this population of microbes dates back to the age of the dinosaurs. And Røy believes that sluggish organisms like these could be far more common than we think. They might exist all around us, but in a world teeming with active microscopic life, these creatures would be almost impossible to detect. "It's like looking for stars during the day," he says. "You see only the sun."

SOPHIA LI

SAINTS + SINNERS

SAINT: VICTORIA SWEET

The physician and historian published *God's Hotel* in April to make the case that healing depends on personal care and patience—a facet of medicine that today's health-care system often rejects in favor of quick cures. The book chronicles Sweet's work in the early 1990s at San Francisco's Laguna Honda Hospital, where she treated elderly and disabled patients for long stretches of time and achieved successful outcomes.

SINNER: JIM LAKELY

The director of communications at Heartland Institute, a think tank that rejects climate science, has stubbornly defended the group's ridiculous billboard (below) likening those concerned about climate change to the Unabomber. Swift backlash led to a scrapping of the ad campaign and the loss of corporate sponsors such as State Farm and Diageo.

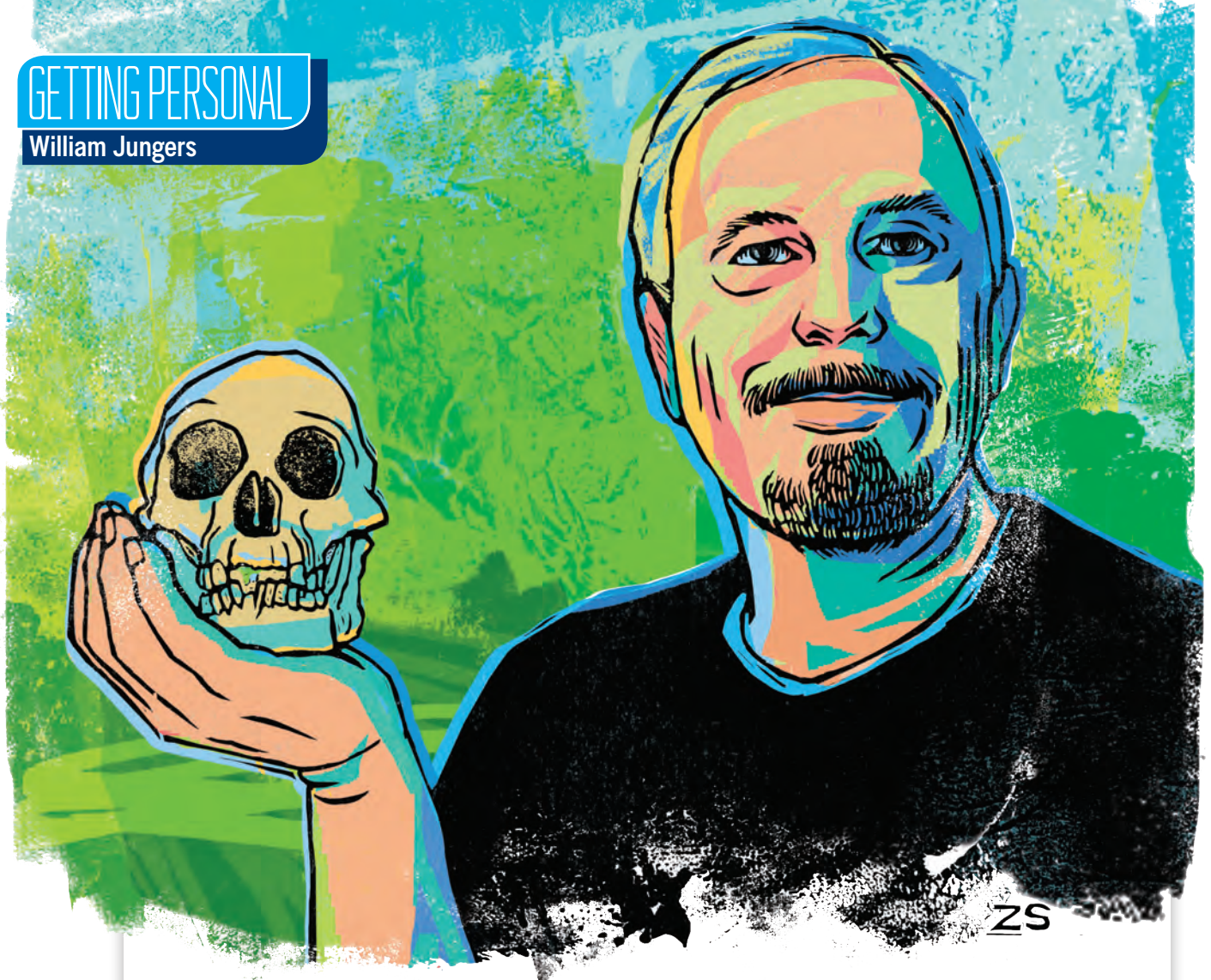
IN PURGATORY: ROBERT SPITZER

The eminent psychiatrist apologized for his past support of reparative therapy to "cure" homosexuality. In the 1970s Spitzer pushed to end the classification of homosexuality as a mental illness, but in a 2003 paper he concluded that reparative therapy was effective. He now admits the study had serious methodological flaws.

THIS PAGE, CLOCKWISE FROM TOP: COURTESY BO BARKER JØRGENSEN; ALEX DI SUVERO/REDUX; COURTESY WIKI; COURTESY DENISE ZMEKHOL. OPPOSITE: ISTOCK

GETTING PERSONAL

William Jungers



How I Explored a Prehistoric Hobbit Cave

The smallest human species that ever lived, *Homo floresiensis,* was astonishing in several ways. It thrived on an isolated Indonesian island from at least 95,000 until 17,000 years ago, outlasting even the burly Neanderthals; nicknamed the hobbit, it stood only about three feet tall and had a puny brain, yet it hunted and crafted stone tools. Fossils of *H. floresiensis*, discovered in 2003, contradicted the accepted theory that size and strength steadily increased as humans evolved. Physical anthropologist William Jungers of Stony Brook University in New York is now studying the remains of these hobbit people.

In November 2006, at Indonesia's archeological institute, it was blistering hot and I was dripping sweat on the spectacular bones of the tiniest human ever to walk this earth. My job was to analyze their anatomical affinities with other human ancestors and use medical imaging to look inside them. We concluded the hobbit was indeed a human ancestor.

Two years later I was invited to join continuing excavations at Liang Bua, the cave on the island of Flores where the hobbit had been discovered. I wish I'd remembered that the cave is at 1,700 feet elevation and gets surprisingly cold at night; I had packed only one long-sleeved shirt. As for my so-called VIP room at a local hotel, it came with occasional hot water and electricity and a monotonous breakfast of coffee, one hard-boiled egg, and something that resembled buttered toast. But the daily trip to the cave was just a matter of minutes.

Liang Bua (meaning cool cave) is enormous, and the large opening drenches some of it with sun for part of the day. Far into its darker recesses, I looked down through layers of time into the deeper sediments, back to the days when the hobbits shared their island with pygmy elephants and relatives of storks.

The best skeleton was found roughly 20 feet down and is accessible only by ladders; the surrounding walls are reinforced by wood planking to prevent cave-ins. Hobbit remains and tools were found in the damp and muddy sediments there, and the bones were extremely fragile, like papier-mâché, when unearthed. The hobbits were likely buried in the cave they lived in by a volcanic eruption, entombed beneath volcanic ash.

My role was to help identify new bones brought to the surface. I could only imagine what daily life must have been like for these little relatives of mine: challenging and sometimes brutal. There were giant Komodo dragons to avoid, and hunting pygmy elephants required strategy, skill, and risk. The cave offered refuge but had issues—falling rocks, occasional floods, and possible penetration by the dragons. It's where the hobbits made tools, bringing in rocks from the riverbed below and chipping off flakes to cut and scrape with. Their story reminds us that only recently did we become the last human standing.

AS TOLD TO JILL NEIMARK

ILLUSTRATION BY ZINA SAUNDERS

Hot Science

What to read, view, and visit this month

Museum
OPEN NOW

I Have Seen the Future

HARRY RANSOM CENTER, UNIVERSITY OF TEXAS AT AUSTIN

If you've traveled on a bullet train, perched on a swooping modernist sofa, or made a martini in a sleek cocktail shaker, welcome to the future—just as Norman Bel Geddes imagined it. Bel Geddes, a 20th-century industrial designer, popularized the idea of a streamlined metropolis with his Futurama exhibition at the 1939–40 World's Fair. Visitors to the fair flocked to see his optimistic, technologically advanced vision of the American city in the then-distant year 1960, with its 14-lane superhighways, radio-controlled cars, and soaring skyscrapers. This exhibit of photographs, films, and models from the University of Texas's collection offers a look back at Bel Geddes's futuristic design aesthetic and the many ways it has shaped our present. *Open now.* EMMA BRYCE

TV

Revolution

NBC

In the latest enigmatic offering from producer J. J. Abrams (*Lost*), modern civilization switches off in an instant, the victim of a worldwide power outage. Fifteen years later, a group of survivors become tangled in a quest to find the blackout's cause. This grim plot rests on a kernel of scientific fact. Geomagnetic storms caused by violent solar flares can overload transformers and cause electric grids to fail; so can electromagnetic pulses, triggered by nuclear detonations miles above the ground. These events could affect an area up to the size of the United States for days or perhaps months—a terrifying prospect, but thankfully far from the global dark age of the show. *Premieres September 17.* FANGFEI SHEN

BOOKS

CONSIDER THE FORK

by Bee Wilson

In this culinary history, food journalist Bee Wilson shifts the focus from the foods people ate to the technology behind their preparation, tracing how humble kitchen implements such as forks, whisks, pots, and stoves shaped our diets, our societies, and our bodies. In Wilson's hands, even hot water becomes interesting: The Maori in New Zealand boiled vegetables and meat in natural hot springs, while cooks in Victorian England insisted on simmering water in pots made of copper, an excellent conductor of heat. One of today's most consequential technologies might be the automatic electric rice cooker, now ubiquitous in East Asia. By replacing the long process of soaking, washing, and closely watching the cooking rice with the flip of a switch, they have freed up untold hours for hundreds of millions of people. F. S.

GRAVITY'S ENGINES

by Caleb Scharf

In the late 18th century, black holes were simply an audacious thought experiment; today we know that the universe is strewn with billions, perhaps even trillions, of these time-bending objects. Although we tend to think of black holes as monstrous devourers of matter, astrophysicist Caleb Scharf uses recent astronomical observations to show that they are the universe's most efficient generators of energy and actually sculpt the shape of every galaxy. For Scharf, whose day job is director of Columbia University's Astrobiology Center, even life on Earth would be impossible without the supermassive black hole that lurks at the center of the Milky Way, regulating the formation of all its stars and planets.

ERIC A. POWELL

THE HALF-LIFE OF FACTS

by Samuel Arbesman

Facts fall apart, some famously so. *Brontosaurus* is not a real dinosaur species; Pluto is not a planet. When you look at them en masse, patterns emerge: Facts die, and are born, at specific, predictable rates. These rates are the subject of applied mathematician Samuel Arbesman's engaging, insightful jaunt across the backstage of scientific knowledge. Packed with interesting tidbits—for instance, more than a third of mammals thought to have gone extinct in the last 500 years have since reappeared—the book explains how facts spread and change over time. It also explores how today's data-soaked reality has yielded high-throughput, automated ways to produce new truths, like algorithms that discover connections between genes and disease.

VERONIQUE GREENWOOD

MOVIE PREVIEW

Looper

It's 2042, and Joe (Joseph Gordon-Levitt) is living the good life as a "looper"—a high-paid hit man for an organized crime outfit from the future that has harnessed the power of time travel to dispose of its enemies. Targets are tied up and zapped back in time from 2072; all Joe has to do is show up, pull the trigger, and collect his reward. But when one of the hits sent his way turns out to be his future self (Bruce Willis), Joe falters and lets him escape, setting off a furious manhunt complete with hover-bike chases, fistfights that challenge our understanding of causality, and lots of good old-fashioned explosions. *In theaters September 28.*

MARA GRUNBAUM

Bruce Willis Improbability Index

Battling his younger self is not the most unlikely thing Bruce Willis has done on-screen. He has never let the laws of physics stand in the way of saving his planet, his species, or his skin.

DIE HARD

Amid the usual death-defying action, our hero uses a "futuristic" touch screen, now less impressive than the devices in everyone's pockets. *Science says: Mildly unbelievable.*

ARMAGEDDON

The Willis character drills into an Earthbound asteroid, plants a nuclear bomb inside, and detonates it just in time to split the rock in two. *Science says: Highly impractical.*

12 MONKEYS

Bruce travels back in time to investigate a pandemic virus, and (nonviolently) crosses paths with his younger self. *Science says: Basically impossible.*

THE FIFTH ELEMENT

Willis teams up with a genetically engineered perfect woman to fly through space, gather mystical stones, and use them to ward off a Great Evil threatening humanity. *Science says: Utterly inconceivable.* M. G.

The statue was constructed in Paris, then shipped to New York.

Statue of Liberty, New York City

When Ainissa Ramirez was growing up in Jersey City, she needed only to look east to see the Statue of Liberty on the horizon. Scaling the 354 stairs to the crown with her family or on class trips, she was always thrilled by the sheer magnitude of the monument. Now a materials scientist and a science education reformer at Yale University, Ramirez appreciates Lady Liberty as much more than an iconic tourist destination. She sees it as the ultimate metallurgical success story, a structure whose combination of materials has allowed it to withstand more than 125 years of the harshest of environments: hot summers, cold winters, and the salt spray of the surrounding sea.

The 156-ton monument stands on Liberty Island, just a 20-minute ferry ride from Manhattan or New Jersey. Unveiled in 1886, the statue was famously a gift from France to America, celebrating 100 years of independence and the Union victory in the Civil War. Its message of freedom for all citizens, particularly former slaves—reinforced by broken shackles that lie at Lady Liberty's feet—resonated with Ramirez long before she understood the science behind its construction.

Inside the statue, it is easy to spot how thin the outwardly imposing structure actually is. "You can see the wavy contour of the robe," Ramirez says, "and if you knock on it, you can hear a sound that tells you it's not very thick," much like hitting a chimeless bell. The statue's copper skin is less than one-tenth of an inch thick, about the same as two pennies pressed together. Auguste Bartholdi, the French sculptor who designed the structure, knew the metal would expand with heat, so he affixed the thin copper sheets to the frame with buckle-shaped copper braces. This gives each piece of copper some freedom to move, while the iron skeleton—designed by engineer Gustave Eiffel, who used the statue's wrought-iron frame as a proof of concept for his eponymous tower—provides structural support. The braces are clearly visible inside the statue, along a seam that runs down the center of Lady Liberty's face.

Visitors were allowed to the top of the torch until 1916, when an explosion set off by German agents sabotaging a nearby munitions dump damaged the raised arm. More recently, members of the public have been permitted as high as the head. (The statue is closed for renovations through late this year; until then, visitors can still tour Liberty Island for an up-close view.)

Flexibility isn't the only reason copper has proved a sound materials choice for the statue, Ramirez says. Bartholdi selected it over heavier bronze to reduce the weight of materials shipped across the Atlantic. And while salt in the air can accelerate corrosion, Ramirez says, it also adds to a protective covering on the statue called a patina, the result of oxygen, carbon dioxide, and other compounds reacting with the copper. That layer formed over Lady Liberty's first 30 years, giving her copper-colored skin its current greenish hue.

The patina hasn't protected the statue from more than a century's exposure to the elements on its own. Engineers have not only patched holes and plugged leaks but made significant structural upgrades as well. Saltwater hitting the statue's iron skeleton and copper skin set up a galvanic cell, Ramirez says, an electrochemical reaction that caused the copper to corrode. Many iron components have been swapped out for stainless steel.

The statue's persistence is, to Ramirez, something of a monument in itself. "It's kind of amazing to me that it's still standing," she says. "Here you have this metal in the most corrosive environment possible—seawater—and it's still there."

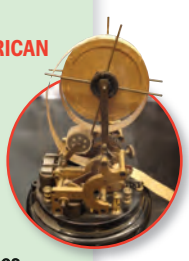
KATE GREENE

THE TOUR GUIDE
Ainissa Ramirez, a Yale University materials scientist, invented the universal solder, an alloy now used in semiconductors that can attach metals to glass, ceramics, and diamonds.

NEIGHBORING SCIENCE SIGHTSEEING

The area around New York Harbor is crammed with touristy activities and world-famous sights, but it is also home to lesser-known destinations that will appeal to scientifically curious visitors.

THE LIBERTY SCIENCE CENTER in Jersey City has interactive exhibits on alternative energy, skyscrapers, and infectious microbes. It also has the world's largest Hoberman sphere, an 18-foot-wide collapsible metal polyhedron that contracts and expands at regular intervals. lsc.org



THE MUSEUM OF AMERICAN FINANCE in Manhattan offers visitors a peek at the inner workings—and occasional malfunctions—of capitalism, with exhibits that explore and explain the intricacies of financial markets, the history of money, and the recent credit crisis. moaf.org

A TOUR OF NEW YORK'S HARBOR HERON ISLANDS offers a sunset glimpse of the coastal birds during their summer breeding season, and egrets, cormorants, and other wildlife year-round. A 90-minute boat ride also provides views of the Manhattan skyline. viator.com K. G.

CLOCKWISE FROM LEFT: ISTOCK; COURTESY LIBERTY SCIENCE CENTER; COURTESY MUSEUM OF AMERICAN FINANCE, NY; RON WATTS/CORBIS; MIRIAM AND IRA WALLACE DIVISION OF ART/PRINTS AND PHOTOGRAPHS/THE NEW YORK PUBLIC LIBRARY/ASTOR, LENOX AND TILDEN FOUNDATIONS

DISCOVER SCIENCE CALENDAR

HOT October

4

World Space Week
Celebrate the launch of Sputnik and the dawn of the space age at hundreds of events here and abroad.
worldspaceweek.org

5

Frankenweenie
Tim Burton updates Mary Shelley's classic to tell the story of a 10-year-old boy genius who brings his beloved dog back to life.
disney.com/frankenweenie

8-10

Nobel Prizes
The Oscars for geeks: Announcements of the Nobel winners in Medicine, Physics, and Chemistry.
nobelprize.org

10

World Mental Health Day
For 2012, the World Health Organization is promoting public awareness of depression, which affects 121 million people across the globe.
wfmh.org

18

Sun Kissed, PBS
The true story of a couple who learn they carry a rare gene that can make exposure to sunlight fatal.
sunkissedthefilm.com

National Cyber Security Awareness Month
With great connection speed comes great responsibility. Learn what you can do to help safeguard your life online.
staysafeonline.org

13-17

Neuroscience 2012
30,000 brain experts descend on New Orleans to cogitate on everything from the ethics of smart drugs to language exposure in the womb.
sfn.org/am2012

14

OCEANS '12 Conference, Virginia Beach
Everything you could want to know about "harnessing the power of the ocean."
oceansconference.org

14-20

Earth Science Week
Tap into your inner geoscientist by planting a garden that measures the ozone layer or by testing the quality of your soil.
earthsciweek.org

NATIONAL SCIENCE TEACHERS ASSOCIATION
Oct. 18. Educators meet in Louisville to craft teaching tools for "Science—Everyone, Everyday!"
nsta.org/conferences

20

National Archaeology Day
Your turn to dig into history.
nationalarchaeologyday.org

21

Orionids
Wake early to see one of the year's best meteor showers at its peak.
astronomy.com/orionids2012

21-27

National Chemistry Week
Nanotechnology demystified: Explore how it can create magnetic nail polish and self-cleaning clothes.
acs.org/ncw

CLOCKWISE FROM TOP: COURTESY SIMON JACOBS/2012 DISNEY ENTERPRISES; COURTESY ARCHAEOLOGICAL INSTITUTE OF AMERICA; COURTESY AMERICAN CHEMICAL SOCIETY; ISTOCK; COURTESY AMERICAN GEOSCIENCES INSTITUTE

This month's calendar is produced in affiliation with the National Science Teachers Association nsta.org
Submit your events to thismonth@discovermagazine.com

BY CLAIRE PANOSIAN DUNAVAN

A Rip Van Winkle Virus

When her friend returns from Africa with a strange skin condition, a doctor suspects a pathogen from out of the past.

AY-YI-YEEE! THE PAIN RUNning down the back of my arm—like a jolt of current traveling a frayed electric cord—caught me off guard. I had never felt a sensation quite like it. On the other hand: Why not? I had just finished a grueling week of hospital consults. My middle-aged frame was simply complaining in a new way, right? I probably just needed rest. "Move over, Ollie," I mumbled. My dozing spaniel made space on the living room couch and I soon drifted off, pain forgotten.

Two days later, my fingers found a roughened patch of skin in the same area as that high-voltage twinge. I craned my neck but couldn't see it. Finally, angling a mirror, I found the telltale lesion: a single nickel-size spot studded with small, fluid-filled bubbles. Aha, I thought to myself. So that explains the burning nerve. That was the moment I realized my body had won a secret battle that I had barely noticed.

But this isn't my story—it's Penny's. Dr. Penny Nelson isn't just a patient; she's a longtime friend who has spent decades tackling malnutrition in developing countries. It's hard to believe the lively pediatrician is now in her 80s. She still travels to a research site in western Kenya where, I have no doubt, the sight of her warm smile, salt-and-pepper hair, and sturdy leather sandals is as beloved to her African coworkers as it is to her colleagues here in the United States. Most recently she has been studying the effects of high-protein foods on child growth and maturation.

Knock on wood, Penny's health is as strong as her will to teach, trek overseas, and live a full, exciting life—and she does everything she can to keep it that way. Last year, however, something strange and disturbing happened to her. Out of the blue, a few days before leaving Kenya, she developed a low-grade fever, knifelike head pains, and one-sided hearing loss.

At first Penny thought an ear infection might be brewing. She started taking a penicillin-type antibiotic her dentist had prescribed her for an aching tooth. Nonetheless, over the next 48 hours the head and ear pain worsened, and strange bumps resembling fleabites began to erupt on a cheek as well as her chin and tongue. Although she couldn't see them, she also felt bumps in her ear on the side where her hearing had been affected.

Could This Be a Tropical Disease . . .

By the time Penny landed in Los Angeles, several bumps had ulcerated, others had coalesced into small, scabby lakes, and a new theory had formed in her mind. Maybe chicken pox virus, which had been lying dormant in her body since she was infected in childhood, had escaped from her cells, multiplied, and started migrating down her local nerve tracts. In other words, she might have shingles—a skin eruption, commonly found on the chest and abdomen, stemming from a reawakened, often decades-old chicken pox infection. It was a logical diagnosis except for two facts. One: Shingles sufferers rarely develop lesions in their ears. And two: One year earlier, Penny had received a shingles vaccine, which re-primes aging immune systems to recognize and fight back against varicella-zoster, the virus that causes chicken pox and shingles.

Also weighing on Penny's mind was the sheer number of exotic blights, from sleeping sickness to snail fever, that a person could contract in the part of Africa's Rift Valley where she was working. After all, when an illness starts in the bush, you can't help but worry. While overseas, Penny was exposed to people, insects, and livestock, all of which can harbor some pretty strange microbial stowaways. What if it wasn't shingles but something more exotic? Because of this nagging worry, within 24 hours of Penny's return, I received an email from her savvy internist, Joan Grant. Suspecting varicella-zoster, Grant had already prescribed acyclovir, an antiviral remedy. But she and Penny wanted a second opinion.

"Penny!" I cried the next morning after meeting my intrepid pal in my outpatient exam room. "Poor you!" Meanwhile, my eyes swept her face and my brain skidded through a list of skin infections both common and rare: crusty impetigo, an inflammatory infection caused by staph or strep bacteria; a rash caused by tick-borne parasitic bacteria called rickettsia; ulcerating sores from the bites of a sand fly laden with microscopic leishmania parasites. For a heartbeat I even considered anthrax acquired from handling infected animal hides, or orf, a pox virus that can pass from sheep and goats to humans.

As my mind whirred, Penny screwed her mouth into a wry smile

Claire Panosian Dunavan is a professor of medicine and infectious diseases at UCLA. The cases described in Vital Signs are real, but names and certain details have been changed.

and raised her eyebrows. "What do you make of this?" she asked, sticking out her tongue. Reddish lesions, like bumps on a pickle, dotted the tongue's front two-thirds on the same side as her blistered cheek. Along with the pocks in her ear, the lesions were the giveaway. To reach those two disparate sites, varicella-zoster virus must have traveled specific branches of the facial nerve. Penny had shingles, all right—but in a far-from-ordinary location.

"Ramsay Hunt syndrome," I breathed, "straight from the textbook. I haven't seen it in years."

. . . Or Something Much Rarer?

In 1907, James Ramsay Hunt, a neurologist at Cornell Medical College, published a seminal paper in *The Journal of Nervous and Mental Disease*. In it he noted that virus-induced inflammation of a knot of nerves ("the geniculate ganglion") near the auditory canal yields a facial eruption in the exact pattern revealed by Penny's exam.

Today, the National Organization for Rare Disorders estimates some 15,000 people experience Ramsay Hunt syndrome in the United States each year. For contrast, an estimated 1 million Americans come down with shingles each year.

Penny remained perplexed. "Why did I get it now? And why here, of all places?" she asked, pointing to her ear. "I was immunized last year."

"Some patients still break out in a modified rash," I mused. "But this is not a place I would expect a vaccinee to develop lesions."

I paused and thought harder. "Did something else stir up the dormant virus near your facial nerve, I wonder?"

That's when an "aha!" look lit Penny's eyes. "How about major dental work?" she offered. "Earlier this spring, I had several implants done."

Of course—it was a perfect, recent trigger. The deep bite of the dental drill and fixing of the titanium "roots" of the implanted teeth would have rattled Penny's immune system, explaining the reactivation of decades-old varicella-zoster virus. It all added up. Now I could safely skip an imaging study of Penny's head and diagnostic scrapings of her blisters to rule out the various tropical diseases.

Sure enough, two weeks later, after she completed the antiviral treatment prescribed by her internist, Penny's lesions were gone. We were both relieved. Without prompt, effective treatment, I estimate that Penny's chance of complete recovery would have been 50-50 or less. Permanent hearing loss, facial weakness, and ongoing pain are common complications of Ramsay Hunt syndrome. Thankfully, my friend experienced none of these.

Now for the coda.

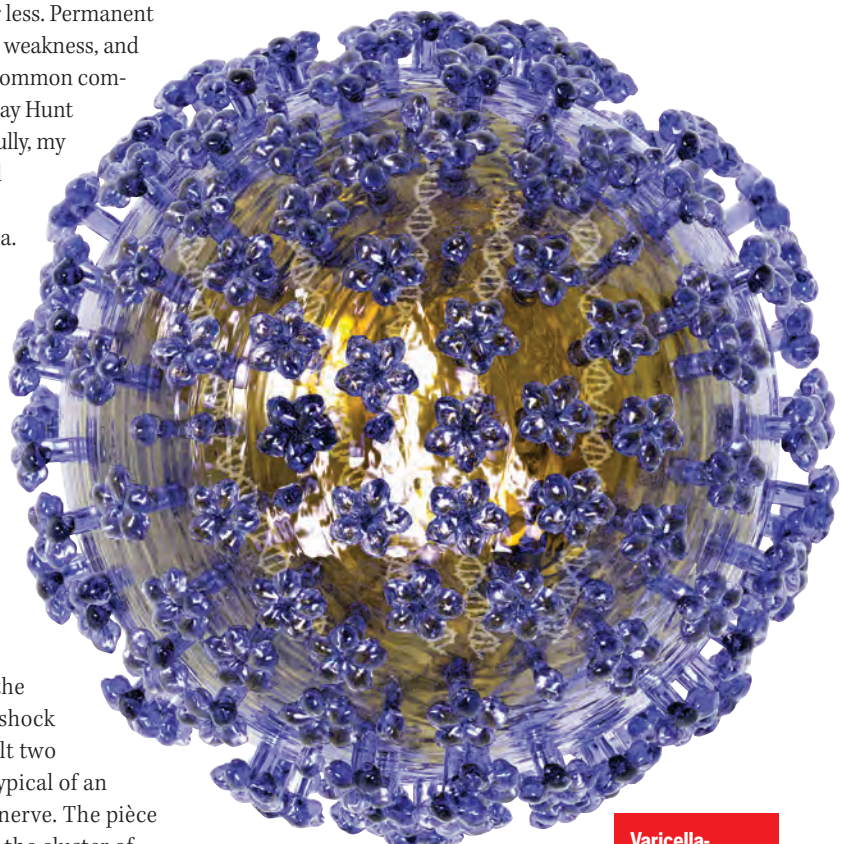
A Dormant Virus Awakes

As soon as I spied the bubbly patch on the back of my arm, I realized I had a "forme fruste"—another modified version—of shingles.

For one thing, the jangling, electric-shock sensation I had felt two days before was typical of an acutely inflamed nerve. The pièce de résistance was the cluster of blisters atop my skin lesion—the hallmark of varicella-zoster and its close relative, herpes simplex, the virus that causes cold sores and genital herpes.

Most people don't realize that shingles can present with a subtle footprint, or even with only nerve pain by itself. "Zoster sine herpete" (roughly translated from the Latin, "shingles minus creeping eruption") is medical lingo for the second syndrome.

In zoster sine herpete, human immune cells quash the virus before it reaches the skin, but not before it infects the nerve. Accordingly, sufferers fail to develop blisters and scabs but still experience the burning spurts of pain associated with full-blown shingles. Proving that varicella-zoster is to blame is not easy. There's still no simple test for the virus if the patient doesn't develop lesions, although many doctors know that varicella-zoster virus is one of the leading culprits for such pain.



Varicella-zoster virus, illustrated here, causes chicken pox, shingles, and—rarely—more exotic nerve damage.

My patients often ask if a major or minor case of shingles protects them against subsequent outbreaks. Not necessarily, unfortunately; varicella-zoster remains in the body's cells even after attacks are treated or resolve on their own. Therefore, the shingles vaccine is currently recommended for healthy people over 60 (today, many experts even say over 50), whether or not they have a history of the disease.

I'm a case in point. Will I stick out my arm for the vaccine after reaching age 60? Absolutely.

CAROL AND MIKE WERNER/PHOTO RESEARCHERS

BY DAVID H. FREEDMAN

Attack of the Drones

Unmanned aerial vehicles like the Predator have been a hit for the military. Just wait until ordinary folks get their hands on them.

THE PREDATOR UNMANNED aerial vehicle, or UAV, has proven a formidable weapon for the U.S. military, quietly lurking in the sky and then zipping in to loose a missile on enemy targets. Its effectiveness raises an important question: When will I have a robotic plane of my own buzzing about that I might summon down to teach a lesson to some of the many deeply annoying people who cross my path? A mild Taser zap or even just a spitball would be fine.

I'm very likely out of luck on this score, due to the bizarre fact that neither Taser zaps nor spitballs share the constitutional protection afforded bullets. So I'll just have to find other ways to make use of the tiny airborne drone that will almost certainly be at my beck and call in the not-too-distant future.

In fact, I'm tempted to head over to a Brookstone right now and pick up a Parrot AR.Drone Quadricopter—a $300, four-rotored, self-stabilizing microaircraft with two video cameras that I can send 150 feet up and down my street to hover outside homes and put my neighbors on notice that their transgressions will no longer go unrecorded. That could keep me occupied until I can afford the more sophisticated $10,000 swinglet CAM by senseFly, which can fly 10 miles, or the $20,000 Draganflyer X4-P, which can carry a 1.5-pound payload—usually a high-end camera—for about 15 minutes.

With a winged camera to beam images to me, I'd also be able to effortlessly inspect my gutters, track my occasionally escaped dog, gauge the lines at the drive-through window, or scope out a dark parking lot before making my way to my car.

But I'll probably hold out on buying a microdrone, because even the Draganflyer is a mere toy compared with what dozens of engineering teams at universities and companies around the world are hard at work on: miniature, autonomous, inexpensive aircraft that you or I could send flying miles to perform any of a wide range of tasks.

Here Come the Flying Tacos

I, for one, can't see what could possibly be wrong with providing personal air-force capabilities to the masses. But if we're going to get truly interesting things done with our drones, we'll need them to fly farther, higher, and longer, as well as to carry more, and do it with much more sophisticated control. All that's in the works, according to Mary "Missy" Cummings, a former F/A-18 fighter pilot who is an MIT aeronautics professor focusing on human interfaces for UAVs. "This is the best thing to happen to aviation since the space race," she says. "We're talking about a technology with a low cost of entry that anyone with a cell phone can use."

The new field is engaging students around the world, Cummings adds, and is engendering some creative ideas. At the top of her wish list: a personal drone to shadow her 3-year-old daughter when she's old enough to walk to school. A hobbyist has reportedly used a drone to track cattle (apparently taking up the slack left by the EPA, which contrary to widespread reports, is not sending drones to spy on farms throughout the Midwest). And one group of students, Cummings says, is drawing up plans for a drone-based taco delivery service.

Affordable microdrones could give ordinary citizens and small businesses access to the kinds of tools that are currently available only to government agencies, well-funded scientists, and big corporations. "If there's an earthquake, we could readily adapt our UAVs to serve as flying cellular towers to restore communications and help look for survivors," says Lora Weiss, a Georgia Tech researcher who heads up a robotics and unmanned systems lab. How many times have I been stuck in camping sites, rural towns, or Houston wishing I had that sort of basic trapping of civilization? My drone could provide it, relaying the Wi-Fi signal from whichever Global Data Communications Node (otherwise known as Starbucks) is invariably sitting nearby, just out of my line of sight.

Name your geeky hobby or passion—weather sensing, wildlife spying, environmental monitoring, terrain mapping—and it's being done right now with a refrigerator-size, multi-tens-of-thousands-of-dollars drone, and will be doable soon with a shoebox-size, multi-hundred-dollar version.

Unfortunately, personal drones have a ways to go. For example, the Draganflyer is, in technical terms, a mere four-taco-delivery drone. That's plenty of food for me, to be sure, but what are the rest of my family and my dinner guests supposed to eat? The limits on payload weight seriously cramp the prospects of a drone-based delivery industry that could go well beyond tacos—perhaps all the way to fully loaded burritos from that taqueria you loved in college, even though it's 75 miles away.

Standing in the way of this dream is basic physics, which cruelly demands that every ounce of extra weight added to a microdrone be accompanied by a big jump in available power. Sticking on a bigger engine is easy, but that means bigger batteries, bigger fuel tanks,

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or shorter flight times. Fixed-wing (airplane-style) drones like the Predator can carry much more weight for their size than rotary-wing (helicopter-style) drones, but can't hover to get a good close-up look at objects of interest, nor could they easily hand off a taco, and they need a runwaylike surface to land.

To keep personal drones in the air longer, higher, and farther, researchers are exploring ways to recharge batteries in flight. "We're going to be able to deliver power to drones wirelessly," says Kurt Barnhart, who heads the Aviation Department at Kansas State University. "We're trying to do it with radio waves here, though others have done it with lasers." Another approach under study, he adds, is "power harvesting"—having drones perch themselves on power lines when they need a boost. Eventually solar power cells may become light and efficient enough to keep drones up indefinitely, at least during the day. I have no problem shifting my taco consumption to lunchtime.

Fast, Cheap, and in Control

If microdrones are to be truly handy, they will also have to be controllable well beyond the one-mile limit of the radio-frequency signals that aircraft like the Draganflyer currently employ. The solution, as it is to so many problems in contemporary life, is smartphones. Cummings and her team have already developed a microdrone prototype that has flown in Boston under the control of a phone-equipped armchair pilot in Seattle. As long as the drone has a cell signal, a Wi-Fi connection, and juice in the batteries, it could stay on mission.

Perhaps even better, personal UAVs need not be under any direct control whatsoever. Incorporating cheap GPS chips and autopilot software cribbed from real aircraft, microdrones are moving toward autonomous flight, allowing you to simply pick a path from a map loaded on your computer or smartphone and then turn the drone loose to fly it. SenseFly's swinglet CAM already allows that sort of pilot- and signal-free operation, which is part of the reason why it can cover more than 10 miles in a single flight.

Before we fill the skies with swarms of autonomously flying cameras, atmospheric sensors, and Mexican food, we need to figure out how to keep them from crashing into one another, not to mention heading into passenger planes. The Federal Aviation Administration currently addresses the problem by prohibiting drones from airspace around populated areas, which is of course where you'd most want to fly them. But the agency plans to allow drones, civilian or otherwise, to share airspace with old-fashioned piloted aircraft by 2015—provided the drones incorporate collision-avoidance technology.

That was the biggest challenge facing drones right now, Barnhart says. "Getting a drone to make an intelligent assessment of the situation and maneuver to avoid any hazards without being told what to do is an enormously complex problem," he explains. But his group and other researchers are well along in developing highly sophisticated software that is up to the task. In fact, he says, the main stumbling block now isn't that drones can't avoid other aircraft, it's that they can't anticipate what goofy, unpredictable action the human pilot of an old-school aircraft might take upon spotting a carne asada taco coming in hot at 11 o'clock high. "We just have to make sure that a drone taking evasive action doesn't end up creating a bigger problem," Barnhart says.

Autonomy has another upside: A personal drone smart enough to avoid other aircraft would be able to seek out and link up with others of its kind. "We're looking at how to have a collection of small, cheap, lightweight, unmanned aircraft coordinate with each other," Weiss says. Why wait for the EPA to send up a $200,000 UAV to spy on your vast ranch, when you and your pals could have your $500 drones split up the chore? Different drones could cover different areas, or carry different sensors. Cummings notes that future microdrones may even be able to self-assemble in the air, perhaps to form a collective aircraft that can cruise long distances more efficiently, so you can monitor a fracking operation a few counties over (or just be really picky about where you get your lunch).

I'm also thinking about coordinated spitball strikes. If only constitutional barriers were as easily overcome as technological ones.

Private drones raise new legal issues. Can you monitor a local chemical plant? Maybe. Spy on your neighbor? Still a bad idea.

ILLUSTRATION BY DAVID PLUNKERT

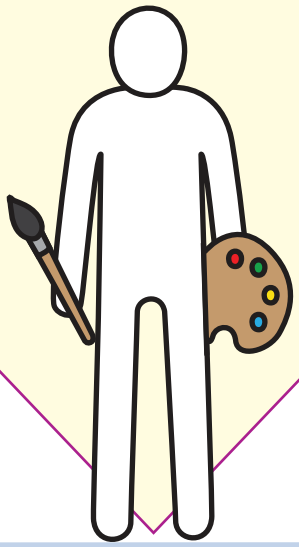
100,000 YEARS OF

An ever-rising population has driven cultural advancement for millennia. What will happen when global

SINCE THE INVENTION OF AGRICULTURE 11,000 YEARS AGO, HUMAN population has trended up—but the boom may be drawing to an end. Birthrates are falling around the world; by the end of the century the number of people on the planet may top out and, in an unprecedented reversal, start to decline. Good news, right? The answer is not so simple. Growing populations are associated with progress; shrinkage has often correlated with cultural decline. One stark example comes from Tasmania, an island off southeast Australia. Nearly the size of Ireland, it was colonized 34,000 years ago by people with sophisticated toolmaking skills who came across a land bridge from Australia. By

ARTISTIC BEHAVIOR APPEARS

Most researchers date the origins of *Homo sapiens* to between 200,000 and 160,000 years ago in Africa. Yet for their first 100,000 years, modern humans behaved like their more archaic ancestors, producing simple stone tools and showing few signs of the artistic sparks that would come to characterize human behavior. Scientists have long argued about this gap between when humans started looking modern and when they began acting modern. University College London archaeologist Stephen Shennan has proposed that cultural innovations were likely due to increased contact among humans as they began living in ever-larger groups. Shennan adapted Henrich's Tasmanian model to much earlier human populations. When he plugged in estimates of prehistoric population sizes and densities, he found that the ideal demographic conditions for advancement began in Africa 100,000 years ago—just when signs of modern behavior first emerge.



100,000 YEARS AGO

STONE TOOLS SPREAD

Population size could explain why the same stone tool innovations show up at the same time across wide geographic regions. Lyn Wadley, an archaeologist at the University of the Witwatersrand in Johannesburg, has worked at the Middle Stone Age site of Sibudu in South Africa, where she found evidence of two sophisticated tool traditions dating to 71,000-72,000 years ago and 60,000-65,000 years ago. Similar tools pop up all across southern Africa at around the same time. Wadley says early humans did not have to migrate long distances for this kind of cultural transmission to take place. Instead, increasing population densities in Africa may have made it easier for people to keep in contact with neighboring groups, possibly to exchange mating partners. Such meetings would have exchanged ideas as well as genes, thus setting off a chain reaction of innovation across the continent.

65,000 YEARS AGO

HOMO SAPIENS TAKES EUROPE

A bigger population may have helped *H. sapiens* eliminate its chief rival for domination of the planet: the Neanderthals. When modern humans began moving into Europe about 45,000 years ago, the Neanderthals had already been there for at least 100,000 years. But by 35,000 years ago, the Neanderthals were extinct. Last year Cambridge University archaeologist Paul Mellars analyzed modern human and Neanderthal sites in southern France. Looking at indicators of population size and density (such as the number of stone tools, animal remains, and total number of sites), he concluded that modern humans—who may have had a population of only a few thousand when they first arrived on the continent—came to outnumber the Neanderthals by a factor of ten to one. Numerical supremacy must have been an overwhelming factor that allowed modern humans to outcompete their larger rivals.

45,000 YEARS AGO

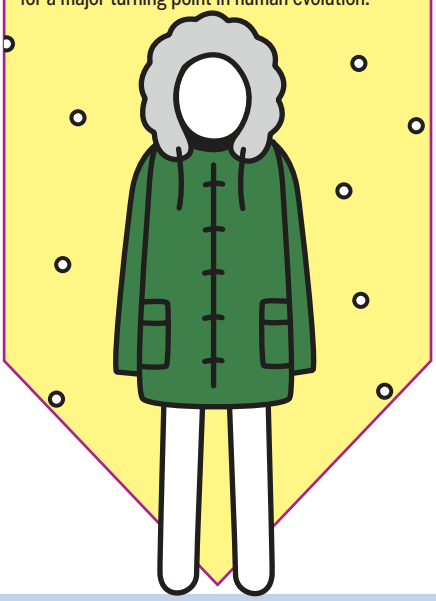
POPULATION

numbers drop for the first time in modern history? The past offers clues. **BY MICHAEL BALTER**

the 18th century, Tasmanians used simple technology, hunting with rocks and crude clubs. In 2004 anthropologist Joseph Henrich used a mathematical model of cultural evolution to tackle this mystery. He concluded that the island's population, about 4,000 in the 18th century, at some point fell below the level necessary for complex skills to be passed from generation to generation. Scientists increasingly think population size and density have had a big impact on human development at certain pivotal points. That continues in the modern world, as young people disproportionately produce innovation, generate economic growth, and finance social support networks for the elderly.

ICE AGE EXERTS A TOLL

By 35,000 years ago, *H. sapiens* appears to have had the planet to itself, with the possible exception of an isolated population of *H. floresiensis*—the "hobbit" people of Southeast Asia—and another newly discovered hominid species in China. But according to work led by University of Auckland anthropologist Quentin Atkinson, human population growth, at least outside of Africa, began to slow down around then, possibly due to the climate changes associated with a new ice age. In Europe, total human numbers may actually have declined as glaciers began to cover much of the northern part of the continent and humans retreated farther south. But population levels never dropped enough for humans to start losing their technological and symbolic innovations. When the Ice Age ended, about 15,000 years ago, population began to climb again, setting the stage for a major turning point in human evolution.



25,000 YEARS AGO

FARMING SPARKS A BOOM

Farming villages first appeared in the Near East during the Neolithic period, about 11,000 years ago, and soon afterwards in many other parts of the world. They marked the beginning of a transition from the nomadic hunting and gathering lifestyle to a settled existence based on cultivating plants and herding animals. That transition helped catapult the world's population from perhaps 6 million on the eve of the invention of agriculture to 7 billion today. Archaeologist Jean-Pierre Bocquet-Appel has surveyed cemeteries across Europe associated with early settlements and found that with the advent of farming came an increase in the skeletons of juveniles. Bocquet-Appel argues this is a sign of increased female fertility caused by a decrease in the interval between births, which probably resulted from both the new sedentary life and higher-calorie diets. This period marks the most fundamental demographic shift in human history.

11,000 YEARS AGO

GLOBAL POPULATION PEAKS

Industrialized societies are experiencing a decline in fertility rates that exceeds the drop in mortality rates. Many developing nations are seeing even sharper fertility drops. As a result, the global population may plateau by 2100. There will still be billions of people to sustain technology, but culture and economics may see major changes.

ILLUSTRATION BY KRISTIN CHAE

PRESENT

POPULATION BOOM

Gray tsunami

Sun City, Arizona, has been a mecca for retirees. But can the model survive as elderly populations explode and retirement becomes a distant dream?

BY JEFF WHEELWRIGHT

On a bright February morning under a blank desert sky, three experts in world population get into a van in Tempe, Arizona, and drive back to the future. From the campus of Arizona State University on the edge of Phoenix, the three head northwest along Grand Avenue, following old U.S. Route 60 out of the city. On either side, what used to be cotton fields and cattle feedlots, and before that catclaw bushes and cactus scrub, has turned into suburban sprawl. The Phoenix metropolitan area, a.k.a. the Valley of the Sun, has grown more quickly than any other urban area in the United States, following an influx over the past decade of Hispanic migrants and white retirees. Due largely to the latter, the Northwest Valley of Phoenix is one of the fastest-aging population centers of the country. >>>

TOM SANDERS

THE DAY STARTS COOL, EVEN COLD. FROST disrupts the tee times on the bright green golf courses dotting the Northwest Valley. Arizona's median age is 34, but at the point where Grand Avenue crosses the dry bed of the New River, palm trees sprout from the sidewalks and the median age jumps to 75. Silver-haired drivers on souped-up golf carts nose into the traffic, one maneuvering fearlessly in front of the university van. Screened by a low white wall, rows of nearly identical single-level houses nestle on tidy, concentric streets. A big hospital overlooks the development like a lifeguard scanning a beach. Welcome to Sun City, Arizona, population 38,000, the once and future retirement mecca, where the whole world seems to be headed.

At Del Webb Boulevard—Del E. Webb was the visionary developer who built Sun City—the van turns and parks in front of the community's historical museum. The three academics get out. They are Michael Birt, 58, a gerontologist and director of the university's Center for Sustainable Health; Jennifer Glick, 42, a sociologist and demographer at the ASU Center for Population Dynamics; and Haruna Fukui, 32, a Japanese graduate student working on her Ph.D. in sociology with Glick as her adviser.

At DISCOVER's invitation, the trio had formed an impromptu panel. They were asked to discuss global population trends, including growth, fertility, and the impacts of immigration. But especially they planned to address the overarching trend of aging, which some researchers are calling "the gray tsunami" because it threatens to inundate the world's health-care systems and sweep away today's social, political, and economic norms. To make the discussion more pointed, it would take place during a field trip to Sun City, the prototypical American retirement community, now entering old age itself. None of the three has been here before, and they are curious to see it.

Population growth, not aging, has drawn the lion's share of public attention, so the panel speaks to that topic first. There was consternation in the media when the Population Division of the United Nations announced that Earth had gained its 7 billionth person in 2011. By 2050 there could be 3 billion more of us, according to the agency's most pessimistic projection. But Glick, the demographer, says, "Let's not make a big deal about that number. The focus should be on the rate of growth and on the eventual turnabout." Although billions of people are still in the pipeline, global population growth is slowing so rapidly that a decline in the population later this century seems unavoidable.

Demographers habitually take the long view, because subtle changes in population trends may take 50 years or more to register statistically. In 1960, the year Del Webb sold the first homes in Sun City, demographers believed that Earth's population was out of control. "We thought it would explode," Glick says. The sense of gloom was captured in 1968 by Paul Ehrlich's best-selling book, *The Population Bomb*, which predicted widespread famine and mass mortality. Instead, an annual population gain of 2 percent has been cut in half and continues to head down. "That's because fertility has declined, which writers of the time didn't anticipate," Glick adds.

The slowdown in growth has been offset somewhat by rising longevity. "People are living longer, 20 and 30 years longer, across the globe," observes Birt, the gerontologist. Greater longevity causes a society to age unless births surge in compensation. In fact, the U.N. called attention to the aging phenomenon in developed nations as early as 1956.

AGING BOOM/FERTILITY BUST

Del Webb was no demographer, but in the late 1950s he saw an opportunity in America's budding crop of elderly. Promoting the then-novel idea of "active retirement," Webb was a very active 60-year-old himself. Tall and lean, a vigorous golfer and baseball fan, he was a millionaire contractor with a common touch. The people who flocked to see his Sun City demonstration homes—100,000 showed up over New Year's weekend in 1960—had had their fill of hard times. These were people who had lived through an economic depression and a world war. The advertisements for Sun City depicted a golden way of life in a place where they could retire and relax, where they would not be frail or sick.

Some of those ads now hang in the Sun City Historical Museum, which occupies one of the first homes to be built here, next to the first golf course. Two vintage golf carts, labeled Him and Her, stand side by side in the carport. Inside, the modest fixtures and furniture of a typical 1960s retired couple are on display. The original cinder-block structure consisted of five rooms totaling just 858 square feet; an addition was put on the back later. The small eat-in kitchen features a boxy electric range and fridge. The sink in the pink-tiled bathroom is very low and the toilet is minuscule, hardly suitable for today's amplified Americans. The three academics smile as they look into the bathroom. "There are no handrails, nothing to grab onto," Glick says.

Sun City's radical idea—to restrict home ownership to people 55 and older—effectively excluded families and children from the development. But recently the policy was updated. Now only one owner has to be over 55, this to accommodate residents with younger spouses. Getting back in the van and touring the quiet, curving streets, with their neat plantings

and pink-tinted gravel, the ASU group sees no pregnant women or kids, no young people whatsoever. Sun City has a fertility rate of zero.

The fertility rate is the number of children an average female will produce in her lifetime. The panelists note that the rate is currently plunging in almost all countries around the world. True, it has not occurred in sub-Saharan Africa, not yet. But for those who specialize in the long view, fertility collapse and accelerated aging have supplanted overpopulation as the most salient demographic trend.

"Take Taiwan," says Birt. "Its fertility rate has gone from about 7 in 1950 to less than 1 today. This trend applies to any country on the development escalator. It's inevitable." As a country develops, initially its death rate declines because of a rising standard of living and better medical care. Next, almost automatically, fertility goes down. "Japan got on the escalator first, and the emerging countries, like Brazil, will get there," Birt continues. "The religion of the country is irrelevant. It's happening now in Iran. It's happening in Catholic countries that oppose birth control, like Italy and Spain. In Mexico the fertility rate is under 3, approaching replacement level."

The replacement rate is the number of children that the average woman must produce in order to replace herself and her mate. Demographers normally define the replacement rate as 2.1 children, the 0.1 increment allowing for infant mortality. It is a pivotal number, indicating that a population is stable, not expanding, and very likely to shrink. Among the 222 countries and territories in the world, two-thirds now have fertility rates below 3, while one-third have slipped under 2 and have begun to contract. Japan, the poster child for extreme trends in aging and fertility, is projected to lose a third of its population in the next 50 years. The most populous nation, China, has a fertility rate of 1.5. Though China's strict one-child-per-couple decree obviously has holes, the policy is having the desired result. India, the second most populous nation, has brought down its growth to 2.6 children per woman. The United States stands at the cusp of population decline because American females are having an average of only 2.06 children apiece.

In those figures lies the turnabout in world population that Glick predicts, and also its senescence, because when people are taken off the population escalator—at the front

In Sun City, Arizona, houses form concentric circles around two churches. Pages 32-33: Tom and Dawn Bussjaege from Southern California, married for more than 50 years.

THIS PAGE: RANDY WELLS/GETTY IMAGES. OPPOSITE: DAVID BALL/CORBIS

The new elementary school was fitted with wheelchair ramps so it could be converted to a senior center when the flow of children dried up.

end, by not being born—those already on it become more conspicuous as they near the top. There is no stopping the process. "That's why we say demography is destiny," Glick remarks. "There's only one exit: death."

Birt describes a favorite graphic of his, derived from a 2007 United Nations publication. He calls it "Solving for X" because of the problem it raises for the world's healthcare systems. Two lines are crossing, the percentage of people over 65 and the percentage under 5. Back in 1950, children predominated in the world; in 2050 the seniors will be on top. "The percent over 65 and under 5 are trading places," Birt says. "We're almost at the X spot." The forecast date for global X to occur is 2017, but each country will arrive at the transition at a different time. "Japan blasted through its intersection years ago," he notes.

Was there a single factor to account for this world-shaking reversal? "Yes," Glick says. "You start educating girls."

Birt agrees. "You start educating women, and they delay marriage and have fewer children," he says. "It's all due to not having children in societies that let women loose." He turns to Fukui, who so far has not spoken. "Fukui-san, you're 32 and not married. That would be inconceivable in Japan 30 years ago." Actually, he does not know for sure that Fukui is unmarried, but he does know Japan, having studied and worked there earlier in his career. With a Ph.D. in Japanese studies, he speaks and reads the language fluently. His calling her "Fukui-san" is akin to saying "Miss Fukui."

THE IMMIGRATION ENGINE

Fukui speaks near-perfect American English, even incorporating a questioning inflection at the end of her sentences. Since becoming a graduate student in Arizona, she goes home to Japan only four weeks a year. She does not object to Birt's appraisal of her, because it is true. Politely, Fukui turns the conversation to *koreika shakai*, or "aging society," a term that has become grimly familiar in her country. Japan has the highest median age in the world, a shade under 45 years, and is in a quiet panic about how to take care of its graying, shrinking population.

CONTINUED ON PAGE 46

Robovie-II from the Advanced Telecommunications Research Institute may one day aid the elderly in Japan, where a shortage of caretakers for the aged is already playing out.

MICHAEL S. YAMASHITA/CORBIS

2062

Global population tops 9 billion; 6 billion crowd megacities

OH, CANADA!
Ice caps melt. Industry booms at top of the world.

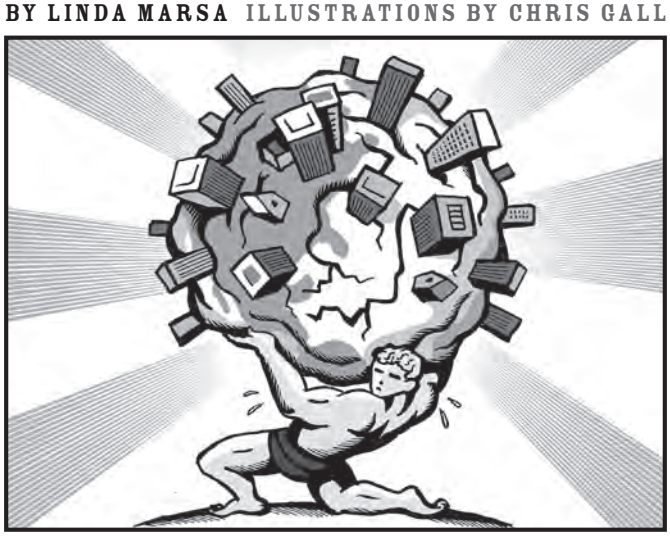
MODERN MATURITY
Earth now home to 2 billion people age 60 and over.

CLEAN ENERGY IN CHARGE
Good-bye coal and oil. Hello solar and wind.

VIVA BRAZIL!
Incomes skyrocket in developing nations.

MEAT, THE NEW DIET
Livestock roam. Croplands decline. Water grows scarce.

BY LINDA MARSA ILLUSTRATIONS BY CHRIS GALL



EARTH'S BALANCING ACT

"Every man desires to live long, but no man would be old." —Jonathan Swift

PLANET OF THE AGED

Gray is the new color of the world population. Today the globe is home to 2 billion people over the age of 60, a group growing five times as quickly as the population as a whole. Five nations contain more than 50 million of these elders: China (440 million), India (316 million), the United States (111 million), Indonesia (72 million), and Brazil (64 million). The aging demographic combined with declining fertility rates—especially in industrial countries—has sent medical costs skyrocketing while economies sputter. The race to attract young immigrant workers, including caregivers for the elderly, is on.

GRAYING GIANTS

GERMANY
Population
2012: 82,302,000
2062: 72,371,000
Life Expectancy
2012: 80.6
2062: 86.5
Elderly (Over Age 65) as Percent of Population
2012: 20.5
2062: 30.1

ITALY
Population
2012: 60,551,000
2062: 57,399,000
Life Expectancy
2012: 82
2062: 87.2
Elderly as Percent of Population
2012: 20.4
2062: 31.4

UNITED STATES
Population
2012: 310,384,000
2062: 421,050,000
Life Expectancy
2012: 78.8
2062: 84.6
Elderly as Percent of Population
2012: 13
2062: 21.9

JAPAN
Population
2012: 126,536,000
2062: 103,241,000
Life Expectancy
2012: 83.7
2062: 88.9
Elderly as Percent of Population
2012: 23
2062: 35

Profile: Japan

LAND OF THE AGING SON

Japan, an economic powerhouse late in the last century, is a shadow of its former self. Because of a low birthrate and increased longevity, its population in the past 50 years has shriveled 18 percent. The workforce has dwindled as much as 36 percent, stalling economic growth. Japan's GDP of $7.1 trillion is a pittance compared with China's $89 trillion (although China now faces its own aging crisis).

Japan's demographic shift has triggered dramatic changes. The country's erstwhile tradition of cradle-to-grave employment, with people working for one company for an entire career, has been phased out in favor of a Western-style meritocracy where jobs, promotions, and wages are linked to performance. High-paid senior executives have been encouraged to retire earlier or work part-time, creating new jobs at better pay for younger generations. Increased tax revenues ease social service burdens, enabling humane eldercare.

With higher wages and greater opportunity, Japanese women have ever more power in the workplace. Flextime and extended maternity leave, European-style child care, and use of fertility aids have helped nudge the birthrate back up. The population, once in free fall, is finally just short of replacing itself.

In Tokyo, still one of the world's largest cities with nearly 39 million people, chains of senior living facilities cater to a huge but active and healthy elderly population. Robots patrol hallways and do menial tasks such as housekeeping, distributing medications, helping residents dress, and ferrying them to doctors' appointments. They even perform minor surgeries. Automated vehicles have restored some of the elderly's lost mobility. Anti-Alzheimer's drugs have drastically improved the quality of life for many.

Spurred by a series of nuclear-power mishaps, starting with 2011's disaster at Fukushima, large-scale solar and wind plants now dot the country.

TOP 5

LEAP IN MEDIAN AGE 2012 TO 2062

1. Iran: 27 to 50 (23 years)
2. Vietnam: 28 to 48 (20 years)
3. Mexico: 27 to 45 (18 years)
4. India: 25 to 40 (15 years)
5. Republic of Korea: 38 to 51 (13 years)

FERTILITY RATE is the average number of children born to a woman in a given country. Fertility rate is like Goldilocks's porridge: It has to be just right (approximately 2.1) to generate a robust and self-sustaining population. Too high and you get a youth bulge that can't be absorbed into the economy. Too low and the shrinking workforce slows economic growth to a crawl.

ARCTIC POWERHOUSES

A warming climate largely eliminated summertime sea ice along the Arctic coasts, exposing vast fossil fuel reserves. The Arctic may hold 22 percent of the world's undiscovered conventional oil and natural gas resources. Canada, Russia, Greenland, Norway, and the United States have all prospered. Canada and Norway are among the world's five fastest-growing nations (alongside Iceland, India, and the United States). Although mounting worldwide energy demand continues to stress the environment, it has powered large-scale development of renewable energy.

What they were saying 50 years ago...
"The traditional extended family is no longer the norm. Younger Japanese are unwilling to take care of their family, and when they get married, they choose someone who won't come with that kind of baggage—which adds to a ticking time bomb."
—Julian Chapple, Ryukoku University, Kyoto, Japan

Profile: Canada

MELTING ICE, LIQUID RICHES

It's hard to remember that Canada's vast Arctic regions were largely uninhabitable 50 years ago. Melting ice has liberated immense oil and natural gas reserves. Tankers and container ships move freely through shipping lanes—once treacherous with ice—between Europe and the Far East. The energy bonanza has spawned Wild West–style boomtowns in the Arctic Circle. The city of Churchill and deepwater ports accommodate ship traffic in agricultural and trade goods, while the Bathurst Inlet serves the diamond mines in the Northwest Territories.

The once sparsely populated Nunavut Territory, controlled by the native Inuit people, has undergone rapid economic and population growth. The infusion of petrodollars has transformed the previously impoverished Inuits into North American sheikhs.

Although 25 percent of Canada's population—roughly 10 million people—is over the age of 60, the population has increased 30 percent in the past 50 years due to an influx of immigrants from Asia, Latin America, and the Middle East. The country presciently established guest-worker programs and recruited heavily among the millions of refugees displaced by drought and heat waves in sub-Saharan Africa and Asia to fill jobs on the new frontier.

ENERGY CAPITALS

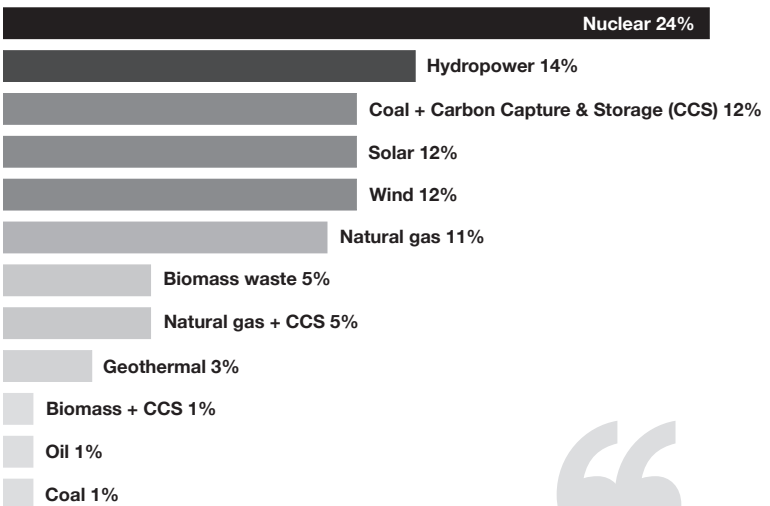
CANADA
Population
2012: 34,017,000
2062: 45,101,000
Oil Reserves
175,200,000,000 barrels*
Oil Produced Annually
3,483,000 barrels*
Per Capita Income
2005: $31,874
2062: $94,358
Gross Domestic Product
2009: $ 1.171 trillion
2062: $4.292 trillion

RUSSIA
Population
2012: 142,958,000
2062: 120,761,000
Oil Reserves
60,000,000,000 barrels*
Oil Produced Annually
10,270,000 barrels*
Per Capita Income
2005: $10,358
2062: $64,350
Gross Domestic Product
2009: $869 billion
2062: $6.34 trillion

*2011 estimates

THE END OF KING COAL

Energy sources that generate the world's electricity*



TOP 5

RENEWABLE ENERGY GENERATION, BY WORLD REGION*

1. Latin America: 87%
2. Africa: 81%
3. Europe: 55%
4. Middle East: 49%
5. United States: 45%

**A best-case scenario prepared by the International Energy Agency, a nonprofit research group whose members hail from 28 countries. Under this scenario, carbon emissions are cut 50 percent from 2012 levels.*

What they were saying 50 years ago...

"Canada is a country that has a sound immigration policy, dignity for aboriginal people, good democratic institutions, and a liberal trade policy codified into law. It is well-positioned in a world where globalized business is the norm." —Laurence C. Smith, author, *The World in 2050: Four Forces Shaping Civilization's Northern Future*

NEW WORLD DYNAMOS

China and the United States still have not been dethroned, but much of the world's economic might now resides with Brazil, India, Mexico, Indonesia, and Turkey. Their rise in status has been driven by young labor forces, investments in education and technology, and thriving middle classes with money to burn. Per capita income in those nations has skyrocketed, raising the standard of living to unprecedented heights but creating ravenous new demand for energy and natural resources.

TURKEY
Per Capita Income
2005: $7,920
2062: $53,560
Gross Domestic Product
2009: $509 billion
2062: $5.93 trillion
Annual GDP Growth Rate
2009-2062: 4.4%

Profile: Turkey

BEACON OF THE MIDDLE EAST

Full admittance into the European Union four decades ago solidified Turkey's position as an economic powerhouse and global player, making it a beacon of modernization for the Middle East. Today this Muslim nation holds the same vital economic role it once did for hundreds of years as the seat of the Ottoman Empire.

Capitalizing on its location on the Mediterranean and the Black Sea, Turkey continues to benefit from a huge influx of foreign investments. It is a transportation hub for

CARBON CAPTURE AND STORAGE (CCS) technology proved crucial for controlling greenhouse-gas emissions starting in the 2020s. Installed at plants that produce iron, steel, pulp, paper, chemicals, and cement, CCS collects carbon gas, concentrates it, and pumps it underground for permanent storage in natural geologic formations. Despite many early fears, very little CO_2 has leaked out from those storehouses.

oil and gas from neighboring Russia, Azerbaijan, Iran, and Iraq, as well as a crucial launching pad for the construction industry throughout Russia, Asia, and Africa. Turkey has also emerged as a leading shipbuilder and a major manufacturer and distributor of heavy consumer goods, including automobiles, home appliances, and refrigerators. Over the past half century, the nation's capital, Ankara, has transformed from a sleepy provincial town into a cosmopolitan city, while Istanbul, long a sophisticated tourist mecca and industrial center, has grown into a megacity of 20 million situated at the crossroads of Europe and Asia.

Shaking off the political convulsions of the late 2010s and 2020s, Turkey made smart investments in education. Its cohort of young, educated workers grew by nearly 20 percent in the first three decades of the 21st century, delivering a demographic dividend that continues to stoke economic engines.

What they were saying 50 years ago...
"A substantial number of people over 65 in Japan, the United States, and Europe will go abroad to work because that's where their skills will still be valued and in demand, and their retirement money will go further. Property developers in Mexico and Tunisia, like those in Florida and Arizona, are beginning to create turnkey retirement communities for expatriates."
—Jack A. Goldstone, director, Center for Global Policy, George Mason University

BOOM ECONOMIES

INDONESIA
Per Capita Income
2005: $3,702
2062: $38,800
Gross Domestic Product
2009: $354 billion
2062: $5.22 trillion
Annual GDP Growth Rate
2009-2062: 4.8%

MEXICO
Per Capita Income
2005: $9,939
2062: $63,300
Gross Domestic Product
2009: $866 billion
2062: $9.46 trillion
Annual GDP Growth Rate
2009-2062: 4.3%

INDIA
Per Capita Income
2005: $3,224
2062: $36,250
Gross Domestic Product
2009: $1.065 trillion
2062: $30.61 trillion
Annual GDP Growth Rate
2009-2062: 5.9%

GLOBAL FOOTPRINT is the size of human impact on Earth's natural resources. In the past 50 years, thanks to education and technology, more than 2 billion people joined the middle class, swelling the human footprint nearly 50 percent. At the same time, millions of acres of cropland have been devoured by population growth and by persistent drought in China and India. But improvements in agriculture have opened up millions of acres of flourishing new cropland in Africa and Brazil.

SURGE OF THE CITIES

The exodus from rural areas, where agriculture is now primarily automated, to cities, where opportunities abound, has continued unabated for decades. Today more than 6 billion people live in cities—about 70 percent of the world's population, roughly double the proportion of a half century ago. The urban shift is especially pronounced in the East, where Beijing, Manila, and Dhaka (the capital of Bangladesh) have nearly tripled their populations since 2012. Meanwhile, cities in impoverished regions, such as Lagos, Karachi, and Mumbai, are bursting at the seams, putting clean water, sanitation, policing, electricity, and health care in short supply.

NIGERIA
Population
2012: 158,423,000
2062: 462,103,000
Fertility Rate
2012: 5.43
2062: 2.87
Life Expectancy
2012: 52.5
2062: 69
Infant Mortality Rate
2012: 87.6
2062: 29.0

Profile: Nigeria

CHAOS NATION

Sitting on tremendous oil and natural gas reserves, Nigeria ranks among the top fossil fuel producers on the globe. But after decades of halting political progress, its democracy remains fragile. Behind the scenes, Nigeria continues to be dominated by oil-rich despots and military strongmen. The nation still feels the effects of the collapse of fishing and farming in its northern regions due to climate change in the 2030s and 2040s, which raised food prices and displaced millions, sending them fleeing into cities in search of better wages.

In Lagos, a sprawling city of 39 million, ostentatious mansions sit next to teeming slums. The dilapidated roads are congested, and refuse collection is sporadic at best. A lack of adequate sanitation and health care has led to recurring epidemics of cholera, malaria, typhoid fever, hepatitis, yellow fever, and AIDS.

A high birthrate has translated into a

INFANT MORTALITY RATE refers to how many infants die per 1,000 born. It is a critical indication of a nation's overall health. In 2062 Afghanistan has among the worst rates (51), while Singapore ranks among the best (2). The United States' rate is 4. Admirably, in the past 50 years the world's average infant mortality rate has fallen from 42 to 18.

population of more than 400 million people, half of whom are under the age of 24. Unemployment and civil unrest are rife, fueled by lack of access to education, persistent poverty, and long-simmering religious tensions between northern Muslims and the relatively affluent southern Christian majority. Robberies, assaults, extortion, and murder are facts of life. Piracy off the coast of Nigeria is rampant as smugglers transport heroin, electronic devices, and electronic waste from Southeast Asia.

But there are bright spots. Over the past 50 years, life expectancy has climbed, the infant mortality rate has dropped by 67 percent, and a once overwhelming fertility rate is coming under control. The exploding population has stoked the economy and created a relatively large, politically influential middle class, which has contributed to a recent improvement in political stability.

TOP 5

METRO AREA POPULATION 2062

1. Delhi (52.9 million)
2. Mumbai (42.7 million)
3. Lagos (39.0 million)
4. Dhaka (36.6 million)
5. Tokyo (34.6 million)

2012

1. Tokyo (37.2 million)
2. Delhi (22.7 million)
3. Mexico City (20.5 million)
4. New York City (20.4 million)
5. Shanghai (20.2 million)

What they were saying 50 years ago...
"Nigeria is going to become the place in Africa. The rising middle class has an interest in a stable investment environment and will put pressure on the government to get its act together and enforce anticorruption measures."
—Jennifer Cooke, director, Africa Program at the Center for Strategic & International Studies

MEGACITY COUNTRIES

CHINA
Population
2012: 1,341,335,000
2062: 1,211,538,000
Fertility Rate
2012: 1.56
2062: 1.88
Life Expectancy
2012: 73.8
2062: 80.8
Infant Mortality Rate
2012: 19.6
2062: 8.3

BANGLADESH
Population
2012: 148,692,000
2062: 192,384,000
Fertility Rate
2012: 2.16
2062: 1.68
Life Expectancy
2012: 69.4
2062: 79.0
Infant Mortality Rate
2012: 41.8
2062: 12.5

THE PHILIPPINES
Population
2012: 93,261,000
2062: 165,507,000
Fertility Rate
2012: 3.05
2062: 1.95
Life Expectancy
2012: 69.2
2062: 78.4
Infant Mortality Rate
2012: 20.9
2062: 10.2

GOING UNDER

More than 150 million people worldwide are at risk from rising sea levels and extreme storms that cause coastal flooding. Overall, sea level is some 35 centimeters (14 inches) higher than it was in 2012. The most vulnerable major cities include Mumbai, India; Guangzhou, China; and Ho Chi Minh City, Vietnam. United States cities at risk include Miami, New York, and New Orleans. Globally, flooding due to climate change threatens to exact a $35 trillion economic toll by the 2070s.

2062 STATE OF WATER & FOOD

To feed a hungry population of 9 billion people, the total production of grains, meat, vegetables, and dairy products has increased 70 percent in the past 50 years. Consumption of water for agriculture—which constitutes more than 90 percent of global water use—has increased 19 percent. Despite that long record of success, agricultural production is stressed by floods, deforestation, drought, urbanization (land-devouring cities), and a growing appetite for resource-intensive meat. More than 4 billion people live in areas at risk of water shortages. The map below illustrates the top threats to agricultural production.

HIGH COST OF MEAT

With rising incomes, meat consumption has increased 73 percent over the past 50 years. But a beefy diet exacts an environmental toll: Cows consume vastly more water and produce far more greenhouse gases than crop foods.

Cubic meters of water (264 gallons) consumed to produce one ton of food

Vegetables: **300**

Nuts: **9,000**

Beef: **15,400**

Meat consumption in 2012: **270 million tons**

Meat consumption in 2062: **470 million tons**

70%

Proportion of global greenhouse gases produced by meat production (2062)

CONTINUED FROM PAGE 36

For a decade, Fukui recounts, stories have been reported of elderly children tending their frail, sick parents, and lately there are reports of seniors dying alone in Tokyo housing projects, some by their own hand, "without notice, and found days, sometimes months, later." Although planners saw the gray tsunami coming when it was still far off, they did not do much to prepare for it, she says. She remembers an elementary school that was built in her hometown when she was young. The new school was fitted with wheelchair ramps and movable partitions so it could be converted to a senior center when the flow of children dried up.

In her postgraduate research, Fukui is studying senior citizen facilities in Phoenix. Sun City perplexes her; she calls it "an extreme example of self-separation." In contrast, Japan mingles its youngest and oldest citizens, placing schools next to senior centers, for example. "We respect the elderly," Fukui says. "Having them around during your childhood is an asset. So society tends to promote that."

If the United States is deficient in Confucian respect for the aged, it has an asset that Japan lacks. Immigration alters a country's population much more rapidly than other factors. Like human hydraulic fluid, immigration pressures the demographic machinery of the world, and the world whines and wheezes in response. Japan's reaction—to restrict foreigners and maintain its ethnic purity—has resulted in a different kind of self-separation. The Japanese are concerned that immigrants will not "fit in," Fukui says. But the needs of its burgeoning elderly have forced the government to relent and let in caregivers from Indonesia and the Philippines.

Over the next 40 years, according to United Nations estimates, the majority of the world's immigrants will head to the United States. "We have higher fertility because we're an immigrant-receiving country," Glick says. Bearing children at higher rates than their hosts and taking lower-paying jobs in hospitals and nursing homes, the new arrivals have the potential to alleviate two problems at once, those of rapid aging and a shortage of caregivers. "In the Anglo world," Glick continues, "the over-65 portion is increasing, but the child population we have is dynamic. So I think there will be enough labor to provide care" for the elderly, she says.

Among Americans over 80–the fastest-growing segment of the U.S. population–half have a neurodegenerative disorder.

The Phoenix sprawl foreshadows the fractured demography to come. Although Phoenix and the state at large are 30 percent Hispanic, that proportion drops to 0.9 percent inside the walls of Sun City and other Arizona retirement enclaves—where residents tend to be white, often from the Midwest. Eight of 10 Arizonans who are 65 and older are white, and their numbers are expected to double in 10 years. Meanwhile, 60 percent of the state's Hispanic residents are younger than 24. Already the majority of elementary schoolchildren are Hispanic. By 2030 half the state's residents will be either under the age of 18 or over 65, an unprecedented gulf dividing groups by both age and ethnicity. It would be hard to concoct a better recipe for social heartburn.

In her sociological research Glick has documented the stresses on Hispanic and Asian immigrants in Phoenix, which intensified during the recession of the past four years. "When you have an economic crisis like we've had recently, it's easy to target a powerless group like immigrants," she says. What is happening in Arizona is a microcosm of global strains, as younger, darker countries confront aging, richer ones.

A NEW OLD WORLD LOOMS

But here it is just another relaxed day on the bowling greens in Sun City. Cars move in a dreamy line along Del Webb Boulevard. The ASU van turns into a shopping plaza and parks in front of Fry's Supermarket. Getting into a space took a bit longer than it might have because the other drivers in the lot are, shall we say, erratic. All the same, nobody honks. Sun City cuts everyone a lot of slack.

Sun City is an anachronism, the three researchers agree, and the pool of potential residents is bound to shrink. "It isn't emblematic any more. This is what the baby boomers' *parents* were retiring to," says Glick.

The boomers who are starting to retire today will live one, two, three decades longer than Del Webb's pioneers. They will definitely need handrails in their houses, if only because, according to surveys, they will want to stay in their homes as long as possible. "Aging in place" is the new mantra in gerontology, Birt says. The trend has reached Sun City and what is now its third generation of residents. Originally the community was a wintertime escape for aging "snowbirds"; today most residents stay in their houses year-round, braving the summertime heat.

As independent as they may strive to be, the baby boomers will not escape chronic illness and the other ravages of old age. Birt has a version of his Solving for X graphic that shows the disease burden on the graying world population. While infectious diseases and illnesses related to poverty are declining, noncommunicable conditions like cancer, heart disease, diabetes, and Alzheimer's continue to increase. Del Webb's own health history illustrates the change. In his twenties he nearly died of typhoid, a major infectious killer of the early 20th century. Advised by a doctor to move to a warm, dry climate, he chose Phoenix. Webb died when he was 75 of lung cancer, a modern lifestyle disease caused mainly by smoking and largely affecting older people.

Scary statistics about the coming tidal wave of debilitated seniors are almost ridiculously easy to generate. Among Americans over 80—who represent the fastest-growing segment of the U.S. population—half have a neurodegenerative disorder. The 5 million who are currently afflicted by Alzheimer's disease will grow to as many as 16 million by 2030. Again, the Phoenix area will spearhead the trend. Already more nursing homes are located in the Northwest Valley than anywhere else in the country. Behind its palm trees and golf courses, Sun City is destined to become a Potemkin village of invalids unless it opens its doors to a younger and more diverse population.

Part of Birt's job at ASU's Center for Sustainable Health is to brainstorm solutions to the gray tsunami. He puts his faith in technology, envisioning that in lieu of human attendants,

YURIKO NAKAO/REUTERS

A favorite activity in Sun City is lawn bowling on the green. But the leisure lifestyle might not suit aging boomers, who are more likely to continue working past traditional retirement age.

medical devices in highly wired households will keep an eye on seniors, reminding them about their medications and monitoring their vital signs, even as they sleep. "Even weighing someone in a doctor's office takes time," Birt says. "If you had all these measurements coming in—the patients weighed at night, in their beds, and you'd track how well they're sleeping at the same time—their care would be more effective." Not surprisingly, the Japanese lead the world in developing robots and other automated solutions to the caregiving crisis.

The trio is having coffee at a small table in the supermarket. Elderly shoppers glide about with their carts, wheels squeaking on the polished floor. Wi-Fi is available in the store, but judging by one question—"Is that a laptop?" a shopper asks, pointing to a computer on the table—the present generation of retirees may not be ready for digitized medical care.

Sun City has spawned plump successors: Sun City West, Sun City Grand, and Sun City Festival, each development pushing farther out into the desert and offering greater amenities to a more upscale class of retirees. But many boomers have not saved enough money to retire and will probably have to keep working well past 65; others, tapping on their smartphones beside their swimming pools, may prefer to keep working anyway. "After all," Glick comments, "retirement is a 20th-century phenomenon. Before then, nobody retired. Two hundred years from now they might be asking, 'What? Retired?' "

The shared vision of retiring to white, middle-class Sun City is defunct. Our current Social Security system depends on a steady stream of young, healthy workers to support it. Immigrant workers will need to come in to aid the elderly, and then they will become elderly themselves. Similar trends will play out in other countries, each on its own timescale and in accordance with its unique culture and circumstance. Culture is flavoring, but still, demography is destiny, as the panelists contend.

If and when a more diverse population moves in to Sun City, something of value will be lost. As Birt suggests, there is a special serenity in a place where no one gets mad at bad driving or confused shopping. The challenge for America as it ages, he says, is for "younger people and older people to be tolerant of the other. Sun City is an environment that is patient with the limitations of elderly adults. I noticed it. I felt it. The U.S. is such an impatient culture…but it is accepting and attractive here. You can see why they stay."

Jeff Wheelwright, a longtime DISCOVER contributor, is the author of *The Wandering Gene and the Indian Princess: Race, Religion, and DNA* (W. W. Norton, 2012).

Brutal Truths About the Aging Brain

A graying world will have more of the experience that comes with age. It will also be slower, fuzzier, more forgetful, and just a bit hard of hearing.

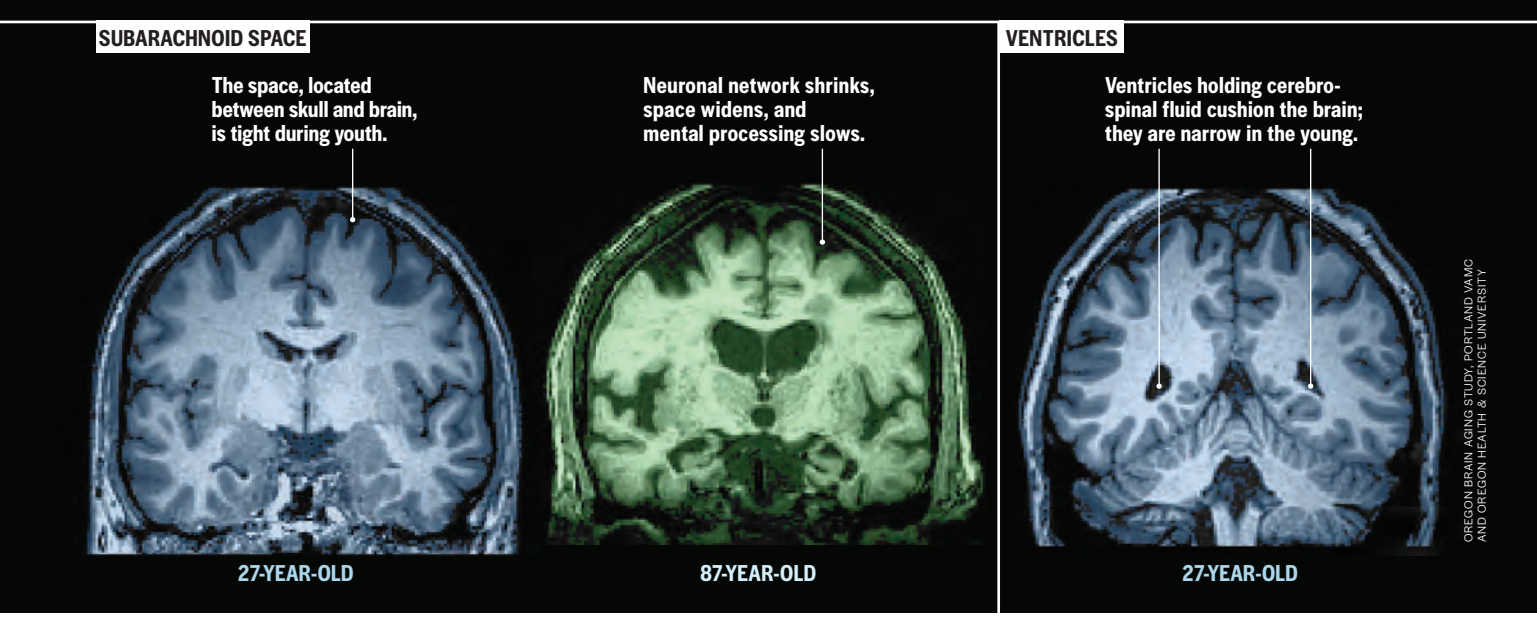
by ROBERT EPSTEIN

AS A GRADUATE STUDENT AT HARVARD University, I worked with one of the most influential behavioral scientists of all time, B. F. Skinner. Beginning in the summer of 1977, we worked together nearly every day for more than four years, designing experiments and chatting about literature, philosophy, and the latest research. Although we were 50 years apart in age, we were also friends. We saw *Star Wars* together, had lunch frequently in Harvard Square, and swam in his backyard pool each summer. "Fred" (from Burrhus Frederic) Skinner was the happiest, most creative, most productive person I have ever known. He was also, needless to say, quite smart.

But the septuagenarian I knew was well past his intellectual peak. One day he gave me a set of tapes of a famous debate he had had with psychologist Carl Rogers in 1962. The Skinner on those tapes seemed sharper, faster, and even wittier than the man I knew. Was I imagining this?

Recently, Gina Kirkish, a student at the University of California, San Diego, and I analyzed tapes of three comparable samples of Skinner's speech: that 1962 debate, a 1977 debate, and a speech he gave from notes shortly before he died in 1990 at age 86. We found that the speech rate dropped significantly over time, from 148 words per minute in the first sample to 137 in the second to 106 in the third—an overall

Tale of the Scans: A Mind in Decline



decrease of more than 28 percent.

Skinner's memory and analytical skills were also declining during the years when I knew him. Sometimes he had no recollection of a conversation we had had only days before. When I tried to talk with him about technical papers he had published early in his career, he often didn't seem to understand what he had written. And he had no patience for anything mathematical, even his own equations. On the other hand, Skinner was still much smarter than most of the people I knew my own age. When you fall from a high enough cliff, you remain far above ground for a very long time.

The sad truth is that even normal aging has a devastating effect on our ability to learn and remember, on the speed with which we process information, and on our ability to reason. Recent studies suggest that the total loss in brain volume due to atrophy—a wasting away of tissue caused by cell degeneration—between our teen years and old age is 15 percent or more, which means that by the time we're in our seventies, our brains have shrunk to the size they were when we were between 2 and 3 years old. Unfortunately, most of the loss is in gray matter, the critically important part of the brain composed of neurons, the cells that transmit the signals that keep us breathing and thinking.

Contrary to what scientists long believed, only about 10 percent of our neurons die during adulthood. The real loss is in the network of connections—the "dendritic trees" that allow a single neuron to be connected to a thousand others. Over the years, 25 percent or more of this network disappears. According to William Jagust, a neuroscientist at the University of California, Berkeley, adults are also losing dopamine, a critical neurotransmitter (the type of chemical involved in transmitting signals between neurons), at the rate of 5 to 8 percent per decade. "By age 80," Jagust says, "you've lost 40 percent or so of dopamine function. When you think about it, it's remarkable that old people can do so well."

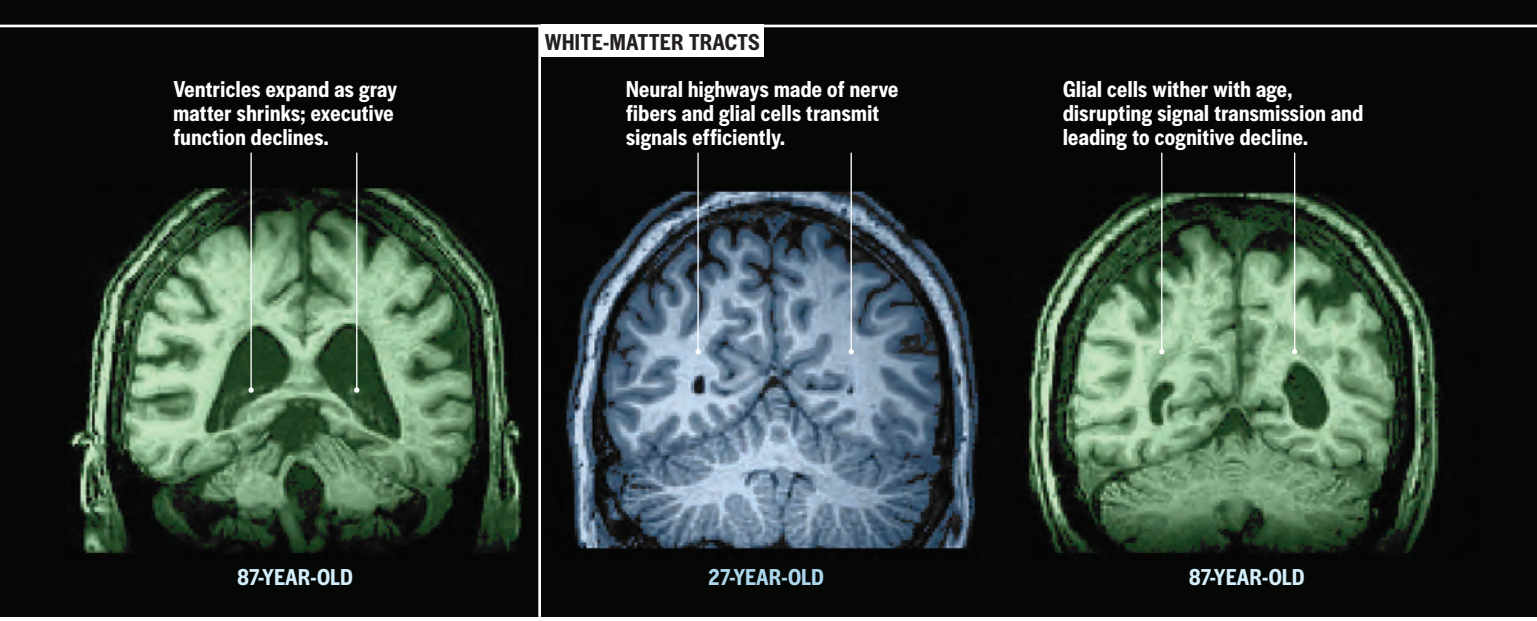
Shrinkage, dopamine depletion, and lost dendritic connections are not the only problems facing the aging brain. Myelin, a substance that insulates neurons, deteriorates, and the number of nerve fibers that carry messages throughout the central nervous system also decreases. Chemical problems—such as an increase in calcium conductance, which might impair neuronal communication—also become more common in older brains, as do problems with gene expression and protein production.

With the global population of people over 80 expected to more than quadruple to nearly 400 million by 2050, the aging brain will become an increasingly big headache for humankind. Here are four cognitive systems that tend to decline as we age. Get used to these changes. You'll be seeing a lot more of them in the future.

1. Senses

Our ability to learn and remember is limited by the accuracy of our senses, our points of contact with the world. But vision, hearing, touch, smell, and taste are not just detection systems. The sense organs also comprise a primitive kind of memory, a temporary storage system or "buffer" for the brain. Much of the input to our sense organs reverberates in receptors, and that reverberation allows even weak stimuli—for example, images flashed so quickly that we have no conscious awareness of them—to impact decisions we make later on. Without the buffering ability of our sense organs, a great deal of information about the world would be lost to us. Unfortunately, as we age, our sensory systems deteriorate, and at the extreme, we become completely insensitive to a wide range of input. For example, high-pitched tones that we can detect at a mere 30 decibels when we are young have to be boosted to an earsplitting 90 decibels for the elderly to hear. (Physics buffs: That's about a million times the energy

Brains atrophy as they age, causing a wide variety of deficits. Neuroscientist Jeffrey Kaye of the Oregon Health & Science University used MRI scans (like those below) to track this process. He says the shrinkage occurs as blood flow slows, diminishing the amount of oxygen and nutrients available to brain cells. That leads to reduced ability to feed and repair neurons and associated cognitive decline. EMMA BRYCE



intensity.) And pupil size decreases as we age, so when it is dim, the elderly person's eyes pick up about a third as much light as people in their prime. Because the deterioration of sense organs limits our access to critical information—speech, text, music, street signs—thinking itself is impaired.

And loss of information is just part of the problem. Research by psychologist Monica Fabiani and her colleagues at the University of Illinois at Urbana-Champaign suggests that in older people the main problem might not be that the sense organ is rejecting input but rather that the brain itself is having trouble filtering out irrelevant information. In a recent study, Fabiani had people of various ages read a book while trying to ignore auditory tones piped through headphones. Overall, the older the individual, the more trouble he or she had ignoring the tones. "The background stimuli may flood your thinking with things that are irrelevant and that you cannot inhibit," Fabiani says. As a result, "you basically lose the capacity to perform tasks."

2. Memory

Most people think of human memory as a single system. But because different kinds of information are retained differently, experts speculate that distinct types of memory systems exist in the brain. Some information stays with us for only a short time—generally no more than a few seconds unless we do something with it. For example, if somebody tells you a phone number and you do not immediately repeat it, it will very likely disappear, never to return. Research suggests the existence of a short-term memory system, consisting in turn of two subsystems: immediate memory (the temporary storage system that holds on to information we don't process in some way) and working memory (a system that allows us to retain information as long as we keep using it).

As we age, our ability to process new information in working memory is severely compromised. In a typical test procedure for evaluating working memory, cognitive aging researcher Timothy Salthouse of the University of Virginia asked people to perform arithmetic computations while also trying to remember the last digit in each problem. People in their twenties were typically able to solve four or five of these problems in a row and still recall the final digits without error. With each decade, performance deteriorated; people in their seventies could typically solve no more than two such problems in a row and still get the final digits right.

One of the simplest ways to assess memory is to read test subjects a list of words and ask them, after a short time has passed, to repeat as many as they can. In a 1990 study, Hasker Davis and his colleagues at the University of Colorado found that people in their twenties could typically recall 90 percent of a list of 15 words after a short delay. With each additional decade of age, the percentage of words recalled decreased. People in their eighties could recall only about half the words.

3. Knowledge

Some information in our short-term memory system is consolidated into a long-term storage system, where it remains available to retrieve for months or years. If a memory of anything from a good meal to a coworker's name persists for 5 years, there is a good chance it will persist for another 40. But as we age, the degradation of sensory and working memory systems makes it increasingly difficult for us to transfer information

CONTINUED ON PAGE 76

How Some Brains Stay **Razor Sharp**

Facing the specter of Alzheimer's disease, the most devastating and widespread manifestation of brain deterioration in old age, worried baby boomers have inspired whole catalogs of brain-fitness books and services. That's good news for publishers, vitamin companies, and computer game designers, but probably bad news for boomers themselves. Elizabeth Zelinski, a gerontologist at the University of Southern California, told me she was appalled at the explosion of miracle cures on the market, adding bluntly, "There's no evidence that anything works." (There is some evidence that some interventions work very narrowly or for short periods of time, but generally speaking, the new industry makes outrageous claims.) And don't hold your breath waiting for neuroscience to rescue you from your upcoming decline. When I asked neuroscientist Eric Kandel, a Nobel Prize winner in medicine, how long it will be before we achieve some reasonable understanding of how memory actually works, he replied, "a hundred years."

On the bright side, some people appear to overcome the ravages of a rotting brain by recruiting new brain systems or structures to take over functions of old ones. Neuropsychologist Yaakov Stern of the Columbia University College of Physicians and Surgeons points out that upwards of 25 percent of people who function perfectly normally while alive have brains that show serious signs of Alzheimer's in autopsy. People with more education have lower rates of dementia, suggesting that brains that get more of a workout create reserves that kick in when frontline systems start to fail.

Kandel, now 82, appears to be one of those rare souls who has somehow managed to keep Father Time at bay. He remains active in research at Columbia University, and his extraordinary productivity and creativity are exemplified by his weighty 2012 book, *The Age of Insight: The Quest To Understand the Unconscious in Art, Mind, and Brain from Vienna 1900 to the Present*. Kandel's daughter, attorney Minouche Kandel, speculates that her father's clarity and energy result from an almost fanatical regimen of healthy food—mainly fish—and regular exercise. "He's lived this healthy lifestyle for as long as I can remember," she says, "and he was doing it long before it was popular."

Through some combination of luck, good genes, and a healthy lifestyle, it is possible, it seems, for a fortunate few to stay razor sharp well into old age. R. E.

DONORS AGAINST DEMENTIA

An Arizona retirement community helps create the world's greatest brain bank.

by JEFF WHEELWRIGHT

ON AVERAGE, THE RESIDENTS OF SUN CITY, ARIZONA, OCCUPY THEIR DOMICILES FOR A DOZEN YEARS. When they depart—almost always by dying—they often leave their brains behind. The stages of physical and mental decline take them from their dream house to a hospital off Del Webb Boulevard, then to a nursing home, and finally back to the medical complex, where researchers harvest their most important organ. Hoping to do good for science, they have enrolled in the Brain and Body Donation Program of the Banner Sun Health Research Institute—widely considered the world's preeminent brain bank.

A large base of well-documented donors in close proximity sets the Sun City program apart from other repositories, which often have scant information about patients who may be scattered and diverse. Here, healthy, active seniors who eventually die of, say, heart disease, can be compared with others who develop neurodegenerative disorders. Because the two sets of subjects have similar backgrounds, lifestyles, and ethnic traits, changes relating to a brain disease should be easier to detect.

Doctors recover tissue during an autopsy at the institute in Sun City.

COURTESY BANNER SUN HEALTH RESEARCH INSTITUTE

The institute is also famed for its crack autopsy team, which responds so quickly that no more than three hours elapse from the time a donor expires to the time that the brain is removed and preserved. "We're not the biggest brain bank in the world, but we have the highest-quality tissue," says pathologist Thomas Beach, the program director, who notes that donors must live within a 50-mile radius of the morgue.

After withdrawing some blood and cerebrospinal fluid for analysis, a team of rotating techs on duty 24 hours a day remove the top of the skull and take out the brain. The next step relies on a device that resembles a bread slicer, which is used to cut the brain into sections one centimeter thick. The slices from the left side are fixed in formaldehyde and those from the right are frozen between sheets of dry ice. Part of the tissue from the formaldehyde sections is stained, pressed into slides, and put under the microscope to verify the brain's condition, healthy or diseased. The rest, light brown and convoluted, may be held in Tupperware containers at the research institute indefinitely. A recent visit to the storeroom turned up a container dated 1994.

These fresh brain sections, kept in carefully monitored freezers, are hot properties for advanced neuroscience research. Because the brain's proteins, DNA, and other molecules are still intact, pharmaceutical companies are willing to pay high prices for the tissue. One of the most prized specimens is a sample of the entorhinal cortex, regarded as the *X* on the brain's treasure map by Alzheimer's researchers because the disease is thought to originate there; the nonprofit brain bank charges up to $1,000 for half a gram.

"Alzheimer's starts at least 30 years before it's diagnosed," says Banner Health neurobiologist Paul Coleman, who works with entorhinal cortex from the brain bank himself. "The clinical trials for treatments have all failed because by the time of diagnosis the brain is so far gone that it's like pouring gas into a car that has no engine." Tissue samples from the ostensibly healthy brains in the institute's brain bank might contain the seeds of the disease and clues to its treatment.

The brain bank has provided raw material to 110 investigators and several hundred studies over the past five years. Asked to name the most important use of the samples so far, Beach thinks for a moment and then describes an ambitious gene-expression study, "the first thorough study of gene expression of individually selected nerve cells in several regions of the Alzheimer's brain." And, he adds, "it's publicly available." Another project enabled the first FDA-approved imaging agent that could be used in PET scans of Alzheimer's patients who were still alive.

In 2005 the institute expanded its autopsy program to include body as well as brain donations. The goal is to correlate the neurological changes found in Alzheimer's or Parkinson's patients with biomarkers of brain diseases in other organs. Scientists using Sun City tissue were the first to thoroughly map Parkinson's lesions throughout the body and brain.

THE URBAN PHYSICIST Geoffrey West

The son of a dressmaker and a professional gambler, Geoffrey West was born just after the outbreak of World War II and raised in relative poverty in postwar England. From those humble beginnings, he went on to a brilliant career in theoretical physics, eventually helping found the Elementary Particles and Field Theory group at Los Alamos National Laboratory in New Mexico in 1974. There he investigated some of the deepest mysteries in physics, including the underlying structure of protons and neutrons, the particles that make up the nuclei of atoms.

Then in the 1990s, at an age when many researchers begin downshifting their careers, West embarked on a brand-new quest, seeking the universal laws that govern biology. After joining the Santa Fe Institute, which focuses on the interdisciplinary study of complex systems, he went even further afield, using mathematical models to investigate the fundamental organization of cities, with surprising results. He and a group of collaborators discovered that simply knowing the population of any given urban area allowed them to accurately predict the nuanced details of its infrastructure and its socioeconomic state. Give West the raw census data from your city—regardless of its history or geography—and he can tell you everything from the number of gas stations in it to the number of patents produced by its inhabitants.

In his offices at the Santa Fe Institute in Santa Fe, New Mexico, where he served as president for four years, West recently sat down for an extended conversation with DISCOVER staff writer Veronique Greenwood. They discussed his history of tackling questions outside his field, the fundamental laws that govern cities, and his belief that population overload is draining global resources, steering us toward socioeconomic collapse.

Q+A

You are an unusual academic omnivore: You have mixed physics and math with biology and population studies. How do you link those fields together in your head?

When I was 10 or 11, I used to go walking on the big chalk cliffs south of London and look across the English Channel. On the horizon I could see the ships getting smaller and smaller. Then, when I was learning trigonometry a few years later, I encountered a remarkable problem: If you know the radius of the Earth, and you're standing on the edge of the ocean, how far away is the horizon? I learned there was a formula that I could use to calculate how far away I could see. I thought: "My God. This is powerful stuff." The rest of my life I have been trying to do that in some sense. So when I look out the window now and see the city and the landscape around us, I ask, "Can we put any of this into mathematics, and can we predict anything about it?"

You moved to America and went to California for graduate school. Was that a shocking change?

When I first saw California, it was extraordinary. Because I came from old, black, dark England, still recovering from World War II. I grew up with bomb sites everywhere. And there still were bomb sites in 1961 when I left and went to Stanford. There I got involved in theoretical work on subatomic particles.

Early in your career, you cofounded the high-energy physics group at Los Alamos. What was that like?

We had some amazing people there. Many of us played an important role in helping to develop what became known as the Standard Model of physics, which is our best mathematical description of the fundamental forces and particles. And because of the huge computing power at Los Alamos, we worked on simulating the theory on a computer rather than using the traditional analytic mathematical techniques of the time.

DAN BURN-FORTI

Physicist Geoffrey West, against the darkling London skyline, has found that cities are organized in mathematically predictable ways.

You were involved with the Superconducting Super Collider, or SSC, a Texas-based particle smasher that would have dwarfed the Large Hadron Collider. That experience helped drive you out of particle physics. What went wrong?

The U.S. government pulled the plug on the SSC in 1993, after $3 billion had already gone in. I was feeling disillusioned, and I was getting old. I come from a working-class family where the men die young. I had always assumed that I would probably not live much beyond about 60, and I was getting into my midfifties. Somewhere, I thought, there should be a formula, based on the underlying principles of how life works, that would let you calculate the life span of a human being.

How did you start on your quest to understand lifespan?

I started to look into metabolism, the chemical processes that sustain life. And what I found were these amazing scaling laws that had been discovered in biology 60 years earlier for which there were no accepted explanations. A scaling law basically represents how various measurements in a system—say, the bodies of mammals—change proportionally as size changes. The first and most famous scaling law is something called Kleiber's law, which describes how metabolic rate, the amount of energy you need per day to stay alive, is related to an organism's size. It turns out that metabolic rate [r] is just the mass [M] of the organism raised to the three-quarters power [$r \approx M^{3/4}$]. A whale, for instance, weighs about 100 million times more than a shrew. You might expect its metabolic rate to be 100 million times greater, too. But it's only a million times bigger, because metabolic rate scales as mass to the three-quarters [$100{,}000{,}000^{3/4}$ is 1,000,000]. The pattern holds with very few exceptions across all organisms. That struck me as extraordinary.

And Kleiber's law is just the beginning. What else did you find about how biological systems scale?

On further looking around, I learned that there were all these scaling laws that people had extracted from biological data. There was one law showing that heart rate decreases as mass raised to the one-quarter power, meaning larger animals have predictably slower heartbeats than small animals. Let's take a whale and a shrew again. The whale is a hundred million times bigger than a shrew, but its heart rate is just a hundred times slower. There was another law showing that life span increases as mass raised to approximately one-quarter, which translates into larger animals having a longer life span than smaller animals. These two laws together say, essentially, that there are the same number of heartbeats in your lifetime whether you are a shrew or a whale. It gives rise to the idea that big animals live very long but very slowly, and little ones live very fast but over a very short period of time.

In 1996 you extended those ideas about the patterns of life at the Santa Fe Institute, where you collaborated with biologists for 15 years. How did that come about and what did you find?

One day I got a call from Mike Simmons, the vice president at the Santa Fe Institute. He brought me together with Jim Brown, a well-known biologist at the University of New Mexico who, in a fantastic coincidence, was looking for a physicist to work with

West at the Santa Fe Institute, in New Mexico, where he explores the hidden math that governs complex networks.

on biological scaling. Along with Brown's student Brian Enquist, we met informally here at the institute at 9 a.m. every Friday, and talked about finding an underlying theory for the scale laws. Ultimately we built a mathematical model of the mammalian circulatory system from scratch, working from basic physical laws that described networks, flow, and so on. When we put all those rules together, we determined that the blood flow rate through any mammal's aorta scales as mass to three-quarters. That allows us to predict the blood flow rate of a mammal just by knowing its size. And the blood flow rate through the aorta defines the metabolic rate, because it's what carries the oxygen. In other words, our mathematical model gave us Kleiber's law.

So what did your mathematical model tell you about how real mammals are constructed?

That the scaling laws they follow are the natural, emergent outgrowth of networks—in this case, a circulatory network—that are constructed according to basic sets of rules.

Do these laws work in other life forms besides animals?

Yes. For instance, we extended scaling laws to plants and trees. We found that the number of branches scales to the radius of the tree trunk, which tells us that even the generic geometry of trees obeys scaling laws. When you walk through a forest, you just see this mess. Trees look like random conglomerations of branches. But in fact there's unbelievable structure there. And these equations describe it.

In 2003 you started studying cities. What led you there?

Cities are obvious metaphors for life. We call roads "arteries" and so forth. But more importantly, they are our unique creations. Santa Fe feels unique, New York City feels unique. They have their own culture, history, and geography. They have their own plan-

DAN PEEBLES

ners, politicians, and architects. Yet when my collaborators and I looked at tremendous amounts of data about cities, we found universal scaling laws again. Each city is not so unique after all. If you look at any infrastructural quantity—the number of gas stations, the surface area of the roads, the length of electric cables—it always scales as the population of the city raised to approximately the 0.85 power.

So even without planning it, every city's infrastructure follows the same mathematical pattern? How can that be?

The bigger the city is, the less infrastructure you need per capita. That law seems to be the same in all of the data we can get at. It is a really interesting relationship, and it's very reminiscent of scaling laws in biology. However, when we looked at socioeconomic quantities—quantities that have no analogue in biology, like wages, patents produced, crime, number of police, et cetera—we found that unlike everything we'd seen in biology, cities scale in a superlinear fashion: The exponent was bigger than 1, about 1.15. That means that when you double the size of the city, you get more than double the amount of both good and bad socioeconomic quantities—patents, AIDS cases, wages, crime, and so on.

And those laws apply to all cities, regardless of location?

This scaling seems to be true across the globe, no matter where you are. I think that what's responsible for it is the hierarchical nature of human relationships. First of all, you cluster in a family. On average, an individual doesn't have a powerful connection with more than four to six people, and that's just as true here in the U.S. as it is in China. Then there are clusters of families, and then larger clusters that form neighborhoods, and so on, all the way up. The structure of this network of relationships could be analogous to the behavior of the networks of blood vessels in the body. They could be the universal thing holding the city together.

Does your discovery have practical implications for urban planning?

You tell me the size of any city in the United States and I can tell you with 80 to 90 percent accuracy almost everything about it. The scaling laws tell you that despite all of the efforts of planners, geographers, economists, architects, and politicians, and all of the local history, geography, and culture, somehow cities end up having to obey these scaling laws. We need to be aware of those forces when we design and redesign cities.

> "Despite all the efforts of planners, architects, and politicians, cities somehow obey scaling laws."

Can your insights about the scaling laws of cities help us understand the impact of population growth and urban migration?

I believe that part of what has made life on Earth so unbelievably resilient—able to evolve and survive across billions of years—is the fact that its growth is generally sublinear, with the exponents smaller than 1. Because of that, organisms evolve over generations rather than within their own lifetimes, and such gradual change is incredibly stable. But human population growth and our use of resources are both growing superlinearly, and that is potentially unstable.

Meaning that our consumption of resources can't keep growing forever?

Right. Our theory suggests we will face something mathematicians call a "finite time singularity." Equations with superlinear behavior, rather than leveling out like the sublinear ones in biology, go to infinity in a finite time. But that's impossible, because you're going to run out of finite resources. The equations tell us that when you reach this point, the system stagnates and collapses.

If your interpretation of population growth is true, why haven't cities already collapsed?

The growth equation was derived with certain conditions that are determined by the cultural innovation that dominates each historic period: iron, computers, whatever it is. An innovation that changes everything—like a new fuel—resets the clock, so you can avoid the singularity a bit longer. But the theory says that to avoid the singularity, these innovations have to keep coming faster and faster.

What are the issues most likely to push us toward collapse?

I think the biggest stresses are clearly going to be on energy, food, and clean water. A lot of people are going to be denied these basics across the globe. If there is a collapse—and I hope I'm wrong—it will almost certainly come from social unrest starting in the most deprived areas, which will spread to the developed world.

How can we prevent that kind of collapse from happening?

We need to seriously rethink our socioeconomic framework. It will be a huge social and political challenge, but we have to move to an economy based on no growth or limited growth. And we need to bring together economists, scientists, and politicians to devise a strategy for doing what has to be done. I think there is a way out of this, but I'm afraid we might not have time to find it.

That sounds similar to the dire warnings of economist Thomas Malthus in the 19th century and biologist Paul Ehrlich in the 1960s. Those predictions proved spectacularly wrong. How is yours different?

I've been called a neo-Malthusian as if it's a horrible word, but I'm proud to be one. Ehrlich and Malthus were wrong because they didn't take into account innovation and technological change. But the spirit was correct, and it is unfortunate that people dismiss their arguments outright. Even though innovations reset the clock, from the work that I've done, I think all they do is delay collapse.

SEX AND THE SO

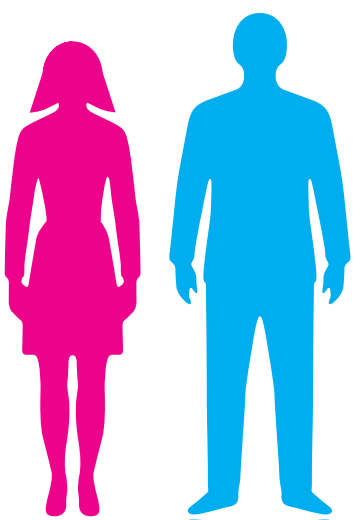
IT MAY BE HARD TO BELIEVE IN THE midst of another contentious election cycle, but the next quarter century in the United States promises to be a period of increasing moderation and stability—at least according to a little-known but compelling theory about how the ratio of available men to available women alters our lives.

Harvard social psychologist Marcia Guttentag began formulating her theory in 1975, after watching Mozart's *The Magic Flute* with her second husband, psychologist Paul Secord, and her two children, Lisa, 16, and Michael, 14. "Nothing is more noble than wife and man, man and wife, and wife and man ... [reaching] to the height of Godliness," sang Papageno and Pamina onstage. Hearing them extoll the virtues of marriage so extravagantly put Guttentag into a kind of "cultural shock," she later wrote. These were the 1970s, after all, when millions of marriages—including both Guttentag's and Secord's first marriages—had collapsed in the chaos of the free love movement spawned during the previous decade.

When Guttentag returned home, she and her daughter listened to songs that were popular at the time, all of which had a "love 'em and leave 'em" theme. Why were views on marriage in these two eras—Mozart's 1790s and America's 1970s—so very different? Maybe, she conjectured, women were in short supply in Mozart's day, and perhaps now, in the 1970s, there were just *too many women.*

That became the title of a book Guttentag began writing soon after she had her insight, which she knew was the most important of her career. For the first time in U.S. history, she soon learned, the "availability sex ratio"—the ratio of adult men to adult women who are available to marry—had dropped well below 1.0, to perhaps 0.7 by 1970. This meant that there were now 10 available women for every 7 available men, an excess of *millions* of women of marrying age. What had caused the sex ratio to drop so dramatically, Guttentag wondered, and what impact did this change have on society?

While busy directing two research centers at Harvard University, Guttentag began *Too Many Women* as a true labor of love. She examined imbalances in the ratio of men to women in various cultures and at various times throughout history and the effects they had on social systems. Among other things, she found that where the sex ratio was high, marriage was stable and women tended to stay home, but where the sex ratio was low (too many women, that is), marriage was unstable and women moved into the workplace.



The dramatic differences between Sparta and Athens during the fourth century B.C. drove the point home for Guttentag. Ancient Athens most likely had a sex ratio between 1.43 and 1.74 (based on a historical analysis) because of rampant female infanticide and neglect. With three men for every two women, women were kept uneducated and at home. Sparta, in contrast, was a military state in which males were removed from their families early on to be trained as soldiers. With an extreme shortage of men in Spartan society, girls received educations and even physical training similar to that of boys, and women controlled and inherited property. Fourth century B.C. Spartan women controlled 40 percent of the land and property in Sparta; Athenian women controlled no property at all.

But Guttentag's book was not to be, at least not the way she planned it. On November 4, 1977, just five days short of her 45th birthday, she died from a heart attack while alone in a hotel room in New York City. Her husband, Paul, completed her manuscript, but the book that finally came out in 1983 was academic in nature, not the mainstream "big think" book she intended. With her death, the book deal she had made with a major publisher disappeared, and sex ratio theory stayed mainly in the obscure recesses of various academic specialties.

BIOLOGISTS HAVE LOOKED AT THE SEX RATIO in animal populations for generations, typically just by counting the males and females in a pack or herd. The natural sex ratio for the American alligator, for example, is about 0.2, or one male for every five females. That kind of ratio makes sense when males fight a lot and female fertility is low.

To study the sex ratio in humans is more challenging, especially if your goal is to determine how the sex ratio affects social systems. Nigel Barber, an evolutionary psychologist based in Birmingham, Alabama, has tested its power more than any other scholar. Among his recent findings: When the sex ratio is low (too many women), women are more slender; when women are in short supply, as was the case in the United States in the 1950s, women are more curvaceous, perhaps because they are trying to look the part of traditional wife and mother. Barber's studies, which often look at patterns in 40 countries or more, have shown the power of the sex ratio in predicting such things as the rate of nonmarital births, the practice of polygyny, and even the likelihood that men will grow facial hair. The more men there are, he found, the more hair they grow to attract mates.

In a study of divorces in the U.S. from 1896 to 1992, Barber reports that the divorce rate

SOURCES: U.S. CENSUS BUREAU, STATISTICAL ABSTRACT OF THE UNITED STATES; CENTERS FOR DISEASE CONTROL AND PREVENTION

CIETY

In the 1970s, a Harvard psychologist proposed that the ratio of men to women shapes culture and politics. Her theory predicts U.S. social trends for the next 25 years.

BY ROBERT EPSTEIN

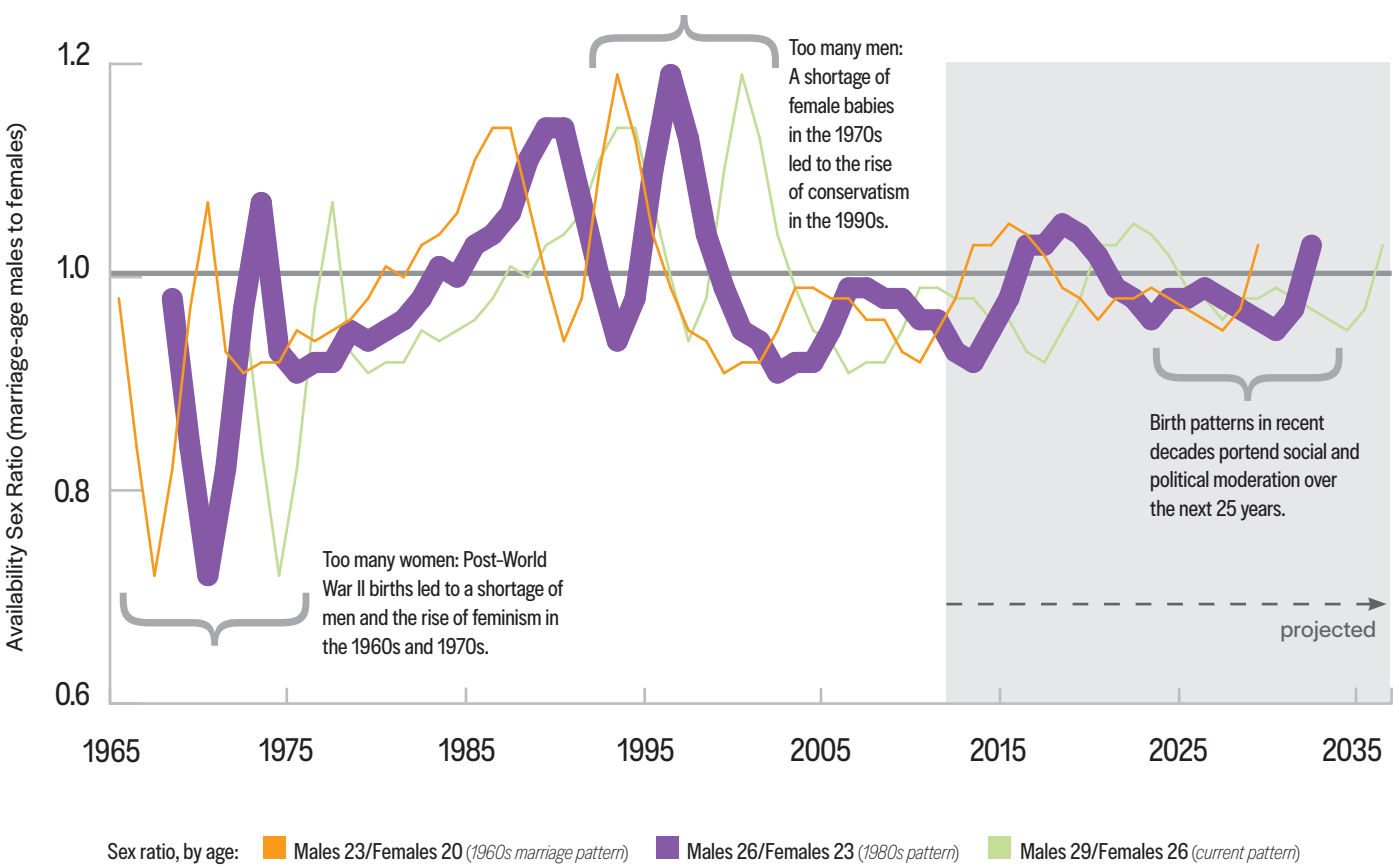
could be predicted remarkably well from the sex ratio. The success or failure of marriage, in turn, ripples though social systems, affecting prevailing values. When there is an excess of available men—as was true during most of U.S. history because most immigrants are male—marriage is generally revered and values are conservative. When available women outnumber available men, women are set free of the home, and values shift toward liberalism. But a low sex ratio also lowers the living standards of women and causes turmoil in relationships, mainly because men typically have more power in society, which they tend to exercise crudely when there are extra women around.

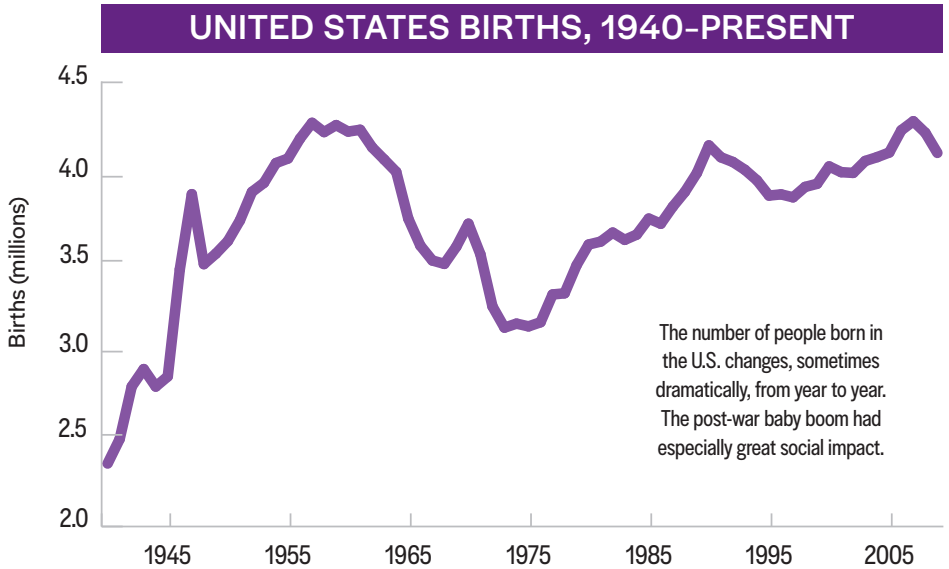
The chaos associated with low sex ratios has been confirmed by several other studies, including a 2010 college-campus investigation by sociologists Jeremy Uecker of Baylor University and Mark Regnerus of the University of Texas at Austin. In a survey of about 1,000 college women, the researchers found that on campuses where women outnumber men, women date less, criticize men more, and are less likely to have a college boyfriend, even though they are also more active sexually.

One kind of chaos that seems to flow from a low sex ratio is counterintuitive. In multiple studies that examine this issue both across countries and over time, Barber has shown that a shortage of men is associated with higher rates of rape, violent crime, and assault. When women are in short supply, men compete for resources like good jobs and fancy cars that make them more attractive to potential mates. But when there are too many women, factors such as an absence of fathers from the home and conflict between the sexes act to raise the level of violence.

THE SEX RATIO IS PUSHED UP OR DOWN BY many factors, including environmental influences in the womb. A 2010 study conducted in the U.K. found that babies born to two nonsmokers were more likely to be male (birth sex ratio of 1.14), whereas babies born to two smokers were much more likely to be female (birth sex ratio of 0.77). Worldwide, the birth sex ratio is generally above one, about 1.07—nature's way,

UPS AND DOWNS OF AMERICA'S SEX RATIO





perhaps, of compensating for the higher mortality rate of males throughout life. By the time people are in their eighties, however, the sex ratio drops to 0.7 or less. Men are in short supply among the elderly.

The sex ratio that is most important in influencing social systems is the one that applies to men and women of mating and child-rearing ages—the availability sex ratio. The fact that women usually prefer marrying men who are slightly older can shift the availability sex ratio up or down almost overnight. This is because the number of people born each year can change dramatically when a war ends or a recession begins. It is this phenomenon, which demographers call the "marriage squeeze," that led to the enormous excess of available women in the U.S. in the generally liberal 1960s and 1970s.

Because of sharp increases in the number of births in the years following World War II and the Korean War, women born two decades later were typically seeking older partners born in years when far fewer babies were born, hence the big drop in the availability sex ratio. So a woman born in 1957, when births were numerous, would, in 1977, be seeking a male born a few years earlier than she—say, in 1954—when far fewer males were born. That's the "squeeze." Conversely, birth patterns in the 1970s created an excess of men in the 1990s. In other words, the nationwide shift toward conservatism, and even the election of George W. Bush in 2000, was predictable from sex ratio data.

A host of effects produce differences in sex ratios around the world and between racial and ethnic groups. The highest sex ratio in the world right now—4.15—is in Qatar, where thousands of men have immigrated to work on construction and oil projects. The lowest sex ratio—about 0.79—is in Djibouti on the Horn of Africa, where an unemployment rate of 40 to 50 percent has forced men to emigrate.

Even the election of George W. Bush in 2000 was predictable from sex ratio data.

Here in the U.S., African Americans have had a low sex ratio since the era of slavery, in part because they have a low birth sex ratio and in part because many black males are in the military or incarcerated. The absence of men keeps many black women living in poverty, bound to the welfare system. Hispanic Americans, on the other hand, have the highest sex ratio of any ethnic group in the country—over 1.5 for people in their twenties—mainly because far more men immigrate than women. The high sex ratio should make that community politically conservative, yet Hispanics generally support liberal politicians, perhaps because liberal politicians are perceived as more pro-minority and pro-immigrant, overriding the sex ratio influence in this case.

In Asian countries, particularly China and India, the ratio of males to females has remained stubbornly and artificially high, causing concern among government officials. Because male offspring are preferred in many Asian cultures, sonograms are now being used to identify female fetuses, which are then aborted in large numbers. The birth sex ratio in China is now an alarming 1.13. The fear in some circles that an excess of men will lead to cultural chaos is actually inconsistent, though, with the views of Secord, Guttentag, and others. Barber's research suggests, for example, that a high sex ratio generally leads to less violence toward women. But the excess of men in China and India has led to new kinds of abuse—women being abducted from Bangladesh, for example, to serve as brides for single males in India, as well as the trafficking of young women within India.

In relatively stable societies like the U.S., the most powerful factor determining the balance of men and women is that marriage squeeze, and birth patterns over the past 25 years make it possible to estimate the availability sex ratio in the U.S. through the year 2035. The trick here is to determine whether the different numbers of people born each year between 1986 and 2010 are likely to cause marriage squeezes in the future.

My computations suggest that we are unlikely in coming years to run into either the liberalism of the '60s and '70s (when there were too many women) or the conservatism of the late '90s (when there were too many men). Instead, we will be trending toward a balance between men and women, and therefore, a prolonged period of moderation in all things political and social: a stable divorce rate, reasonable satisfaction in relationships, and greater gender equality.

Absent major natural or human-made disasters that are sex-selective or extreme changes in immigration patterns, the next quarter century should be a time of relative calm. Marcia Guttentag would be pleased.

Robert Epstein, senior research psychologist at the American Institute for Behavioral Research and Technology, provided original research for this piece.

Recipe for Immortality

An expert in synthetic biology explains how people could soon live for centuries.

BY GEORGE CHURCH AND ED REGIS

The yearning for immortality dates back at least to ancient times. As human brain size increased rapidly over the past million years, our ancestors began to think increasingly about the inevitability of death and the redemptive possibility of everlasting life. Ancient pharaohs, queens, and kings used every means to ensure their vestigial persistence through future ages. They had themselves enshrined in legends, songs, and poems; they had their remains preserved in vast pyramids.

Part of the reason for that yearning may lie in the fact that people already live so long and with such self-awareness. Our species is distinctive in its ability to remember and to predict future events based upon past experience. Before the invention of writing, and even afterward, reliable predictions required the presence of memories in a living person. People well past their reproductive years could add value to their tribe by remembering early warning signs of rare phenomena, such as drought, locusts, and disease.

In modern times our learning extends even further. It includes postdoctoral studies and on-the-job training that may continue well into our 60s. Like our ancient predecessors, we enshrine the most important bits of our collective knowledge, only in more sophisticated embodiments: scientific publications, books, music, video, websites. Nevertheless, when people die, their wisdom—the memories and mental processes that produced that knowledge—dies too.

Throughout history, death was associated with assaults, sickness, and privation. Now an increasingly common cause of death is aging. As the wealth of nations increases and exposure to toxins and infectious agents drops, aging will become the cause of most disease, debility, and death. At the same time, many more people will remain active beyond the age of 100. So, beyond the fear of death, there are practical reasons to explore extending our healthy years.

Scientists have much to learn from the longest-lived humans, many of whom will have their DNA sequenced in the next two years. The effort to extend life—and, even more, to extend life's youthful, vigorous phase—is a clear opportunity for synthetic biology, the technique of extensively engineering the genome. [George Church is a leading researcher in this emerging field.] The cure for aging will probably require a thorough redo of our genome.

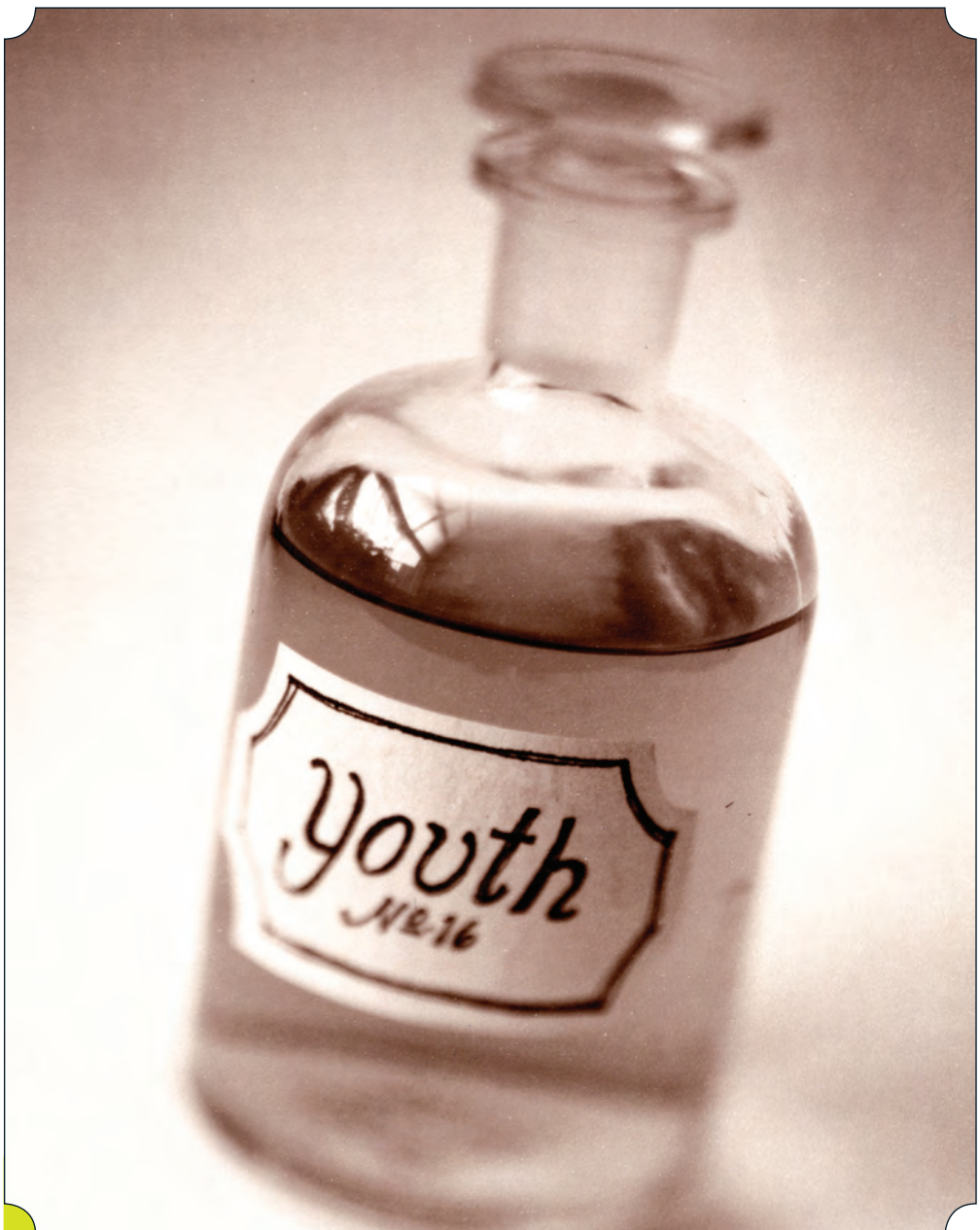
We can scour the best of the biosphere for ideas. Species run the gamut when it comes to longevity. Some adult mayflies live, dance, and mate for all of three hours. At the other extreme, some specimens of bowhead whale appear to be more than 120 years old, judging from the age of harpoons lodged in their flesh. The oldest known fish, a koi, was a scarlet female named Hanako, who reportedly died at the age of 226 years on the memorable date 7/7/77. The hard-shell clam *Arctica islandica* can live more than 400 years (judging from annual shell rings) in nearly freezing water, where rates of metabolism are very low.

But it might be possible to evade aging entirely. In one widely cited publication from 1998 ("Mortality Patterns Suggest Lack of Senescence in Hydra," published in *Experimental Gerontology*), Daniel Martinez claimed that hydras—small aquatic animals that look a bit like cacti—may not undergo senescence at all and may be biologically immortal. More astonishing yet is an organism that appears to do something otherwise unheard-of in the animal kingdom: It gets younger. This ability is possessed by *Turritopsis nutricula*, a jellyfish that can return from its sexually mature (medusa) state back to a younger (polyp) state. An entire population of such organisms can do this repeatedly and swiftly, escaping biological death through aging, although members of the species can still be killed through predation, accident, and disease.

This bizarre menagerie of extremely long-lived, possibly immortal, and fountain-of-youth organisms leads us to consider humans. Like these organisms, we are built of cells, and some of those cells can be immortal too.

The possibility of cellular immortality is also suggested by the case of Henrietta Lacks, an African American woman who suffered from cervical cancer and died on October 4, 1951, at Johns Hopkins Hospital at the age of 31. For research purposes, cell samples had been taken from her cervix. They were code-named HeLa cells, using the first two letters of her first and last names.

Prior to Lacks's death, Hopkins researcher George Gey found that HeLa cells could easily be grown in lab glassware and kept alive indefinitely. As other researchers asked for samples, the cells replicated, grew, and proliferated so wildly that they often took over and wiped out cell lines of any kind with which they happened to come in contact. Descendants of the original HeLa cells are still alive today, more than 60 years after they were removed from Henrietta Lacks. HeLa cells are so biologically aberrant in their chromosome makeup that they could never be used to model immortal human life, but they nevertheless point the way.



P. E. REED/GETTY IMAGES

> “The cure for aging will probably require a thorough redo of the human genome.”

The healthy cells most capable of making at least some aspects of individuals immortal are germ cells. The germ line, produced by egg and sperm, is the only part of us that naturally survives us in our offspring. Germ-line cells are the all-time champions of cellular survival. We can trace their DNA back through billions, possibly trillions, of binary divisions, back to the dawn of life itself.

Cloning germ cells, then, looks like one possible path to human immortality. Germ cells from a mature animal can be reset to embryonic form; these are the famous “embryonic stem cells.” The embryonic cells can develop into replacement organs in the lab or be injected into an egg, where they develop as a viable embryo and are literally born. We can also freeze such cells to keep them healthy and youthful; when the aging donor needs repairs to a damaged genome, the cells could be tapped. Scientists have already cloned more than 20 species, including carp, mice, sheep, monkeys, cattle, cats, dogs, and horses. Cloning is sometimes viewed as dangerous or unethical, but many new technologies are initially perceived that way, then accepted and finally widely embraced—airplanes, for example, or in vitro fertilization.

At present, the main argument against human cloning is that occasional difficulties observed in cloning other animals suggest that human clones would sometimes be born with medical abnormalities. This is a serious concern, but it doesn’t mean human cloning can never happen. In one plausible path to that end, veterinary scientists continue to get better at cloning agricultural mammals until the success rate is extremely high. When the chance of error in animal cloning becomes lower than the error rates of natural reproduction, human cloning trials could become socially and ethically acceptable or even recommended.

But even without cloning, life extension could be achieved. For instance, medical researchers might succeed in creating complex tissues and organs derived from patients’ own stem cells. These so-called pluripotent stem cells can be derived from a variety of adult cells and be guided into almost any other tissue type. Synthetic biocircuits made of DNA and encoded proteins could be inserted to detect and repair (or kill) cells with mutations known to cause cancer or aging.

In a related approach, new translational codes in the genome—which define how a cell uses DNA to construct proteins—could make organisms resistant to all viruses. Viruses do their damage by entering cells and using the cellular machinery to replicate themselves. They are able to do this because both the

viruses and the host cells make use of the same genetic code. But if we changed the code of the host cells, it would thwart the virus's ability to replicate, and so make the host immune.

That may sound like science fiction, but the Church lab at Harvard has already changed portions of the genetic code of *E. coli* bacteria to repel viral attacks. Beyond this, we could take the DNA repair abilities from *Polypedilum vanderplanki*, a fly whose larvae can survive complete desiccation and extremes of heat and cold, and transplant them into human cells.

Ultimately, synthetic biology could free us from obsolete limits set by evolution. We could repair damaged tissue and direct the growth of new tissues to create built-in body and brain parts that could interface with electronic devices. For example, some cells could be engineered to light up and signal if a person is experiencing inflammation, unusual neuronal activity, etc., functioning as noninvasive diagnostic devices.

Globally, life expectancy and the onset of old-age symptoms have been steadily improving at a rate of three months per year. A nearly perfect straight line for the past 170 years! Impressive, but some biotechnologies are improving at up to a tenfold rate per year, meaning that a dramatic change in the slope of that line could happen soon.

The route to long-lived humans will arrive via milestones that we can only guess at. Genome engineering in clinical trials today may become routine by 2014. By 2016 we may have ways to rejuvenate neurons, such as by injecting them with fresh nuclei from engineered stem cells, to make them young again. Or we may have developed miniature electronic circuits capable of monitoring and stimulating neurons, which might be used to augment memory or maintain neural functions during the replacement of neuronal nuclei. Within a decade, we should be able to use these technologies to read and alter the state of neurons for an enormous fraction of the cells in human brains. (We can already do this for dozens of neurons in humans with epilepsy.) This could lead to much longer life spans—semi-immortality, extending progressively toward an unknown limit—both for our cells and for our minds.

With such breakthroughs potentially less than a decade away, now is the time to consider what a world of semi-immortals would look like. One of the most commonly expressed objections to the prospect of human immortality is the unintended consequences of overpopulation, including the fear that long-lived individuals would take away jobs from younger people. Yet our resources have kept expanding.

Thomas Malthus died in 1834, worried about the survival of the world population, which then numbered 1 billion people and was growing by 5 million per year. Today the population stands at 7 billion and is growing by 75 million people per year. But instead of the global starvation and misery that Malthus envisioned, we have seen widespread rises in wealth, standards of living, health, and life expectancy. As economist Julian Simon once explained, "Resources come out of people's minds more than out of the ground or air. Minds matter economically as much as or more than hands or mouths. Human beings create more than they use, on average. It had to be so, or we would be an extinct species." Fertility rates tend to decrease with increasing life span even if the number of fertile years per person increases, which counters the trend toward population increase associated with increased life span.

> "Like a species of jellyfish that reverts to youth, we may one day evade old age."

The vision of a nearly immortal populace squelching the job prospects of youth is reminiscent of 19th-century Luddite concerns about machines' taking over jobs from humans. The likelier scenario is a population implosion marked by increasing numbers of older, healthier citizens, and more women in positions of power, a situation that could be beneficial for child rearing, philanthropy, diplomacy, and other aspects of our civilized life. Look for our values to change: With children a rarer resource, educators may become among the highest-paid workers in the world. Instead of teachers, grammar school kids might be coached by personal tutors on the model of the British university system.

One thing that makes for a robust and long-lived species is diversity among the population. That is as true for *Homo sapiens* as for any other. Personalized tutorial education might yield the advantages of greater human diversity, allowing us to embrace larger spectra of personality types, perceptual and cognitive idiosyncrasies, and high-functioning autistics, bipolars, ADHDs, and hyperthymesiacs (who can recall autobiographical events in extraordinary detail). People with such traits occasionally succeed today, but in the future could do so more often.

Our new semi-immortals, people of indefinite and unknown longevity, would be a diverse population resistant to all viruses, known and unknown, all other pathogens, and all forms of cancer, autoimmune diseases, environmental toxins, and even radiation—that last attribute particularly handy for space travel. We can acquire such abilities by importing into the human genome the genetic sequences from other

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JAY BLAKESBERG/GETTY IMAGES

A Love Supreme

In a future America, longevity infusions swaddle the rich—and one doctor seeks her place in a divided world.

by KATHLEEN ANN GOONAN

ELLIE SANTOS-SMITH GRABS A clean white coat as spring dawn brightens her worn oriental rug and streaks with sun her only luxury, a grand piano.

She runs a comb through her jet-black hair, cut short because she thinks that makes her look older. Her smooth skin glows with 20-ish health, though she is 47. Patients distrust young doctors. Nanomed infusions keep her body young, her mind sharp, and mitigate her crippling agoraphobia. She has worked hard to be able to live in a minuscule apartment in The Enclave, a safe, low-population-density bubble in Washington, D.C. In this small, pure paradise the incredibly rich claim more cubic feet than most people in the world can dream of, dine on rare organic food, and ingest the most finely tuned infusions.

She hates herself for needing this. But she does. If she is to help anyone, if she is to put her hard-won training to use, she does. She can walk to the Longevity Center for her frequent infusions and, after that, to her job as an emergency physician at Capital Hospital without being trapped in a car, a subway, a plane.

Her phone rings. "Dad?" His voice gravelly, odd. Not that she's heard from him in a long time.

"Hi, hon."

She thinks blue for a moment. His eyes, tear-shimmered blue beneath a thatch of sun-whitened hair, all those years ago. He had been abruptly summoned from his marine biology kingdom the day her mother was murdered, as Ellie watched, during the First East Coast Riot. He'd fled back to his undersea haven soon afterwards, leaving her to Grandma and boarding schools.

"Can we talk later? My infusion is overdue; then I'm working emergency till seven," she says. She imagines him in the teak cabin of his Key West–anchored sloop, stubbornly aging.

"Never mind." He hangs up.

Same old game. She should be used to his gruff elusiveness, but it always hurts. Her father, a celebrated marine biologist with a worm named after him, quit academia once she got her college scholarships and spent decades painting bizarre ocean creatures, gaining a small international following.

Downstairs, the doorman smiles. She steps out into her safe haven, a few tree-lined blocks of historic mansions, townhomes, restaurants, and shops bounded on one side by Connecticut Avenue and patrolled by security professionals (thugs, to her mind) for which she pays a hefty neighborhood fee. They keep out the homeless, the hungry, the desperate, and the different. Once outside this discreet, invisible boundary she will have to pass through a few blocks she calls The Gauntlet, which throbs with the dense crowds that now fill most of the cities on Earth, before reaching the hospital where she works. Only her nanomed infusions keep panic at bay.

In front of her, a lone bicyclist splashes through puddles, and nearby Don Stapleton descends the broad stairs of Forever, a

SCOTT BARROW/CORBIS

1900-vintage condominium mansion of 30 wealthy centenarians, some of whom worked hard to establish The Enclave. He waves. "Doc! Lovely morning!"

Trapped. She could swear he hacks her schedule. White dreads halo his dark, handsome face. "Coffee on the veranda?" She glances over at the broad Victorian porch, with wicker chairs, hanging ferns, and eight limber residents sun-saluting as Ella Fitzgerald sings.

Six hundred million centenarians—C's—are the last recipients of Social Security. It is the lifeline of most C's but only slightly augments the wealth the people in Forever acquired during successful professional lives.

"Thanks, but I'm late."

"I'll walk with you. We have a new offer."

Her throat constricts. "Sorry, but no." The work, she knows, would be a nightmare. Perpetually on call for a household of detail-oriented hypochondriacs; crushed by constant, whimsical, impossible demands. She walks faster toward her job in the Hospital Center, where her patients are poor and in desperate need of her skills. They are the people to whom she has devoted her training and her life.

Don persists. "You got Mrs. Diyubski an emergency infusion. Cut through red tape, saved her life—"

"I'm not a boutique M.D."

"You are a nanomedicine expert. Fewer patients might be less stressful for you. That could be a great change, given your phobia."

Nosy bastard. He smiles. "Public information. I'm sending the offer." The ping in her ear registers its reception, and Don falls behind.

In a few blocks she is at Dupont Circle. The implanted microchip that gives her access to The Enclave now signals with a low beep that she is unprotected. She takes a deep breath. Masses of children, teenagers, everyone young. Shanties, ever-milling crowds, food lines, rank odors, and a constant assault of raised voices, ugly music, honking horns.

The phone. Her father, calling back. "We need to talk. I'm dying."

A break in her stride. "Where are you?"

"Hospice at Sunnyland. Hepatocellular carcinoma." The words roll off his educated tongue.

"When were you diagnosed?"

"Three months ago."

She rages. "Why didn't you call? It's not too late. Regeneration infusions—" Her brain teems with nanomed therapies. Most out of his financial reach, since he has stubbornly avoided anything other than mandatory insurance, and his age—85—precludes expensive life-extending measures.

"I'm ready to go, Ellie. They give me two, three days. I just want you, now."

I wanted you then. All those years. You were gone. You didn't love me. "I need to talk to your doctor."

That gravelly laugh. "You're kidding, right? I was diagnosed by a nurse-practitioner after an ambulance ride foisted on me by a well-meaning neighbor. I'm in the benevolent hands of the state. Deprived of a death at sea. No docs at Sunnyland."

No surprise, that. "I can't jump on a plane."

"It's OK. I reap what I've sowed."

Her urge to get to him, to see him, brings her to sudden tears, surprising her. But she'd been taken off a plane in a straitjacket when she was 12. Even first class didn't help.

"You don't understand. It's not that." It's not our past, our hopeless inability to communicate.

"Hon, you may not think so." He hangs up again.

She's always urged her father to live with her. "In that bubble? No thanks." A relief, and they both know it. She can't live with people. Her short marriage hammered that home. Her only close companions are dead musicians and her piano, which she plays long into the night.

Ellie surfaces from their conversation angry, without her insulating defenses, to endless oncoming faces, roaring buses, choking exhaust. She's powerless. He's stubborn, and she's let his stubbornness kill him. *You can control everything else in your life, but you can't control your father.*

Damned if she can't.

She recalls recent nanomed updates and rearranges these components in the work of art that is her own mind. Heart pounding, she makes it to the door of the Infusion Center, passing the block-long line of those hoping for an insurance reprieve, shows her card, and slips inside.

The receptionist is new. Ellie takes a deep breath and rolls the dice. It's not like her, but she has no choice. "Add 17 and 43."

"That's not allowed."

"I'm Code R-1." Ellie hates exposing herself to pity. Her expensive infusions are government compensation to victims of the deadliest riot in U.S. history—the riot in which Ellie's mother died, the riot that began a decade of turmoil around the time the world's population passed eight billion.

Few people, not even professionals like Ellie, can afford what she gets: life extension, nanomed components updated in real time. Nanomeds could be manufactured cheaply. Prices are kept high. The official explanation is the cost of R&D and the experimental nature of nanomeds. The real truth is overpopulation and a fear of more C's.

She lies on a gurney in the infusion room. Designer nanomeds maintain her phenomenal memory—a double-edged sword, for those memories trigger panic. After Ellie witnessed her mother's murder, her psychiatrist pressured her father to allow therapeutic memory mediation—erasure. Her father refused, wanting Ellie to have that choice when she was older. For that she is thankful. Those memories make living in her bubble imperative, but they are her. Her infusions are a balancing act, holding the possibility of neuronal damage, but she has the authority to design her own cocktail.

Adding 17 and 43 will radically change the balance, removing her fear. She will probably be able to leave her bubble, get on the plane. She is not sure what other changes might occur. Her carefully constructed life could fall apart.

"Doc, you know you can't do this." John, her regular nurse.

"You know I can."

"It's dangerous. This isn't like you. The latest bulletin—"

"I know. Paradoxical effects from these latest upgrades. I have to fly tonight."

John sighs. "You want to listen to jazz during the infusion?"

"Of course." Slight sting of needle. She closes her eyes, and memories assail her.

Lavender dusk limned by a horizon of bare brown trees. Stopped on the Beltway. Ten lanes of static oncoming lights, the usual soothing interlude between kindergarten and supper. Ellie strapped in her seat, killing 3-D aliens, Mom up front chanting "A Love

Supreme" with John Coltrane, head bobbing, still in her white coat after a day in the hospital. Then she gasps.

Striding down an exit ramp: An army of people flows among the cars. Ragged clothes, muffled chants. A bat, smashed windows, her mother sprawled over the seat screaming, "Don't hurt my niña!"

Blood spatters her mother's white coat and Ellie's video screen.

Years later, driving while in medical school: A flood of oncoming lights. The world under construction, always—cranes, barrels, trucks of supplies to accommodate people, who keep appearing, appearing, filling every space in great towers and on vast artificial islands. Ellie wants to help, like Mother. Driving through fear will make her strong. Finally, strength fails. She flips; can't function. The usual infusions are ineffective. City centers needing her expertise have become unlivable.

In D.C., after a long, difficult search, she finds her oasis. The price? She can't ever leave.

"Doc?" She opens her eyes and wonders—*when did I stop being able to live?* She sits up. "I shouldn't be jittery right after an infusion."

"You knew you were taking a risk. I'll take a blood sample."

"No time. And John?"

"Doc?"

"Don't use Coltrane again."

"I didn't."

There is no way she can avoid her shift in the emergency room; there is no one to take her place. She leaves the Infusion Center and makes a plane reservation for a flight after her shift while striding New Hampshire Avenue. Only a block to the hospital, and now, post-infusion, throngs effuse love, do not seethe with malicious intent, do not lie in wait to make deadly, unexpected moves.

She arrives at the hospital and is relaxed, surprised to be breathing easy as she is scanned in and checked for weapons. She pushes her arms into her white coat and grabs a chart. It is paradoxically frightening to feel so utterly good in this whirring hellhole, where daily she strives, with heartbreakingly limited success, to deprive death of its staggering bounty.

She slips inside a curtained space. "Mr. Billings?" He lies on the exam table, unshaven face bruised, a police officer beside him. "What happened?"

The cop says, "He started a bar fight. Not the first time."

"Not true." Billings glares at the cop.

"He never remembers."

"She broke my arm."

"That's a lie."

Ellie says to the cop, "You'll have to step outside."

"He's dangerous. He just exploded—"

"Out." She begins her exam. "Your arm?"

"Hurts like hell."

Ellie shines a flashlight in Billings's eyes. "Where'd you get this scar on your forehead?"

"Incoming. Ten years ago. Everybody else died."

"Sit up." She hammers his knee. "Been treated for PTSD?"

"Borderline. They won't pay."

"I'm ordering pain meds and an X-ray of your arm. I'll be back in a little while."

Her next patient needs a kidney update. She sits on the table, puffy, staring at her knotted hands. Ellie has become a technician, enjoined from stepping outside finely drawn boundaries. Care is rationed. HMOs have made medicine a corporate algorithm, doing the greatest good for the most people.

Her M.D. gives her the power to override tics in the system. She knows how far she can push the limits and which procedures are too expensive, will tip the balance and get her censured.

The kidney treatment is out of bounds. Ellie hesitates, approves it. "You'll feel better soon."

Tears in the patient's eyes. "I thought—"

"New protocol."

Boutique doctors practice as they see fit because the rich bypass the corporate algorithm. As she leaves the patient, she

> The elderly in these high-rises did not watch their pennies. They cannot catch the wave of technology for a long-term ride.

can't help checking Forever's offer, the one Don Stapleton keeps pushing. Staggeringly huge. She couldn't possibly provide services worth that. The C's would devour her. And she would be treating them…forever. The same people. Her emergency skills would atrophy. A trap.

But one more override and she might be out on her ass. She knows that her recklessness is because of her infusion. She just needs to make it to the end of her shift. After an hour she gets Billings's results. "Fractured ulna. This bone," she tells him, touching it. "I'm ordering a mending infusion."

"Hear that?" Billings yells. The cop is startled awake.

Ellie asks Billings, "How would you like to stay out of bar fights and feel better?"

"Can't afford it."

"I only need your consent. You'll get neuroplasticity meds and counseling. You have to promise me you'll go to counseling or it won't work."

"You sure, Doc? I mean—"

"I'm sure."

Billings reminds her of her father—at the mercy of the unfeeling algorithm. He'd had choices, though, more choices than Billings.

She has always avoided thoughts about the tangle of their lives. *Except*, she thinks, surprising herself, *they come out through my fingers. Hours and hours and hours at night. They come out when I improvise, play jazz. They're not as far away as I think.*

Filled with momentary wonder, she draws back the curtain, where the eternal next patient sits. Everything seems so preternaturally sharp, so full of potential for too much thought that she aches for her shift to end.

On the red-eye, Ellie stares out the window of the plane at a solid unending glare of light all the way down the East Coast, imagining all those people, and does not go fetal. She does not scream.

She has not called her father.

As she steps from the cab at Sunnyland, she feels as relaxed as if she had run 10 miles on a treadmill. High-rises surround her, receding grids of light blocking any other view. Twenty thousand elderly live here on 30 acres, a template reproduced nationally. Those living here did not watch their pennies. They cannot catch the wave of technology for a long-term ride.

Ellie will always have a job. The life she

worked for is bright and assured, an enviable personal future. A future where she will hide from time, emotion, and change.

Irked at her thoughts, she grabs her bag and enters the lobby of her father's building. On the hospice floor, visitors nap in chairs, maintaining vigil. Outside her father's room, a whiff of whiskey as she passes two chatting, weathered men in fishing caps. Inside, strings of colored lights, low revelry, and Coltrane's sax wailing for the second time in 24 hours, this time no dream. Her fingers flex in a near-unconscious riff. She spots her father in a reclining chair.

His face, frighteningly thin, is lit on one side by a blinking blue light. A faint smile plays across his face; a beer is in his hand. She flies to him: "Dad!"

He blinks, grins. Flash of overwhelmingly blue eyes, and she is once again 5. "Ellie! Come to see the old man off after all, eh?"

"I'm getting you out of here."

"Good god, Ellie. I'm getting morphine! Don't mess with it."

"It's not funny. Give me a more detailed diagnosis."

"Certain and welcome death. Interment in the sea. Making room for younger people who are happy to be alive."

"You can recover."

Her father says gently, "This is hospice. Four days of rationed grace. They know how to mete it out fine. No needles, no tubes, no machines. I skipped that. I probably got whatever I have long ago when I was torturing rare marine organisms instead of coming home to see you. Fair play."

"Fair play? I missed you, Dad, of course I did. I *needed* you. But that has nothing to do with your choosing to die. What have they done so far?"

He shrugs. "Two infusions last month. Standard issue. They didn't work."

"You didn't call."

He speaks slowly, as if to a child, with equal emphasis on each word. "I just didn't want to."

She grasps it all, his terrible stubbornness and hers, and opens her phone.

"What are you doing?"

"Calling an ambulance."

"Ellie, Ellie. No one will pay for it. And where do you think you'll take me?"

"An infusion clinic. I'll pay."

"Not even you have that much money."

"I have a new job offer. I'll take care of you. I'll sell my apartment—it's worth a lot. We can live in the centenarian house—beautiful—interesting people. You'll love it—"

"Don't tell me what I'll love."

She sees a sheen of sweat on his forehead. She is a bit ashamed, but not enough to stop. She shouts, "You're a foolish old man!"

He smiles. "I hope so." He waves. "Keep talking, everybody, she's just my daughter." Chatter resumes. He says, quietly, "You might think that I don't know you, Ellie, but I do. Remember that summer you spent with me after college, when you were deciding what to do with your life? Yes, too brief, but I know you like I know myself." He pauses for a breath. "You have to do what moves you, and what moves you is your job. As it is. Whatever you're doing, however crazy it looks to me, it works. Don't sacrifice that job to help me. I don't want it.

"Second point—don't interrupt, I'm getting tired. I've had a great life. Despite our... tragedy. I don't want to live anywhere but on my boat. If you do anything without my consent, I will never forgive you. I'm serious. And I don't ever again want the kind of pain I've had the past six months."

> The new infusion lets it surface, but that does not make it less valuable: She hears her mother as if she were music, Coltrane.

"I wouldn't have let you have that pain!" To her surprise, Ellie begins to cry. "You hid it from me. You didn't want my help. What has my life been about if I can't even help my own father? You'd rather die than have my help." She drops to the bed, covers her face, and sobs.

"Ellie, look at me."

She wipes her face on her sleeve. "Sorry."

"Don't be. I haven't seen you cry since your mother died."

"You haven't seen me much. Holidays. Birthdays." She hears the 10-year-old in her voice, her two annual summer weeks at sea with her father ending once again.

"Fair shot." He pauses. "It's over. The oceans are polluted beyond repair."

"You can help restore them! You—"

"This place that seems so awful to you, this is what it's like everywhere now. Even worse. I've been all around the world. I've done my part. I'm proud that a worm is named after me." He draws a deep breath, coughs, looks at her squarely. "I'm proud of you. Your mother would be so proud of you." Another long pause while she grabs a tissue, blows her nose, wipes her face. "You can do one thing for me."

"What?"

"Let's move this party to my boat. I was kidnapped. I don't want to die here. Order somebody to bring a piano to the dock and you can play me out. I haven't heard you play in a long, long time. It's like heaven to me. It always reminds me of the first time I went diving."

"But—"

"That's all I want of you. We can't get back the years I wasted. Do this for me, please."

She waits for the old anger, the old rage, to bubble up and spew out. Her hand moves toward her phone, then stops.

You know how to improvise.

Instead of the ambulance call, there is a memory, one of many she has hugged to herself all these years, refusing to release it. It's the new infusion that allows it to surface, she knows, but that does not make it any less valuable.

A winter day at her grandmother's. The holidays. She is playing the piano. She begins with one learned set piece, Bach.

Then there is a shift. She hears her mother as if she were music, Coltrane, jazz. She threads new notes to Bach, adjusts cadence, moves into new space. Improvises. Loses herself in sound, falling snow, her father, leaning on the piano as tears roll down his face.

She remembers that she played for hours.

She looks directly at him, seeing him as if for the first time: a person separate from herself, from her needs, from her ways of making her own life small and safe.

She nods. "All right, Dad. Let's go."

Kathleen Ann Goonan is an author and a professor of literature at Georgia Tech.

BY EMILY ELERT

North America Spills Its Guts

A mobile seismic observatory, rolling out slowly across the continent, is piecing together a startling picture of what lies beneath.

DEAN LASHWAY CLIMBS OUT OF A FRESHLY DUG PIT ON AN alpaca farm in eastern Tennessee. The equipment he has just installed is listening intently. At the bottom of the six-foot hole is a seismic sensor that records vibrations from around the world. Soon it will pick up the thud of a vault lid closing, the dull patter of dirt being shoveled on top, and the drone of Lashway's van driving off. As human activity fades, the sensor will be left to eavesdrop on the crash of distant ocean waves, the rumble of faraway storms, and above all the quiver of nonstop mini-earthquakes—Earth's constant seismic hum.

The seismograph is one of some 400 that make up the Transportable Array, a network of sensors that has been working its way across the country since 2004. From its initial installation along the West Coast, the array has been repeatedly uprooted and relocated farther east. Today it covers a 400-mile-wide swath from Minnesota to Florida. Each sensor records vibrations at its post for two years, relaying data to a computing facility at the University of California, San Diego, until a crew digs up the instrument and transports it to the next site. When the array reaches the Atlantic seaboard next year, it will begin collecting the final batch of data needed to complete the first high-resolution, 3-D map of the 50-mile-thick North American continent. Initial results are already helping scientists understand the processes that shape continents and tear them apart, so they can reconstruct our planet's geologic history and predict its future.

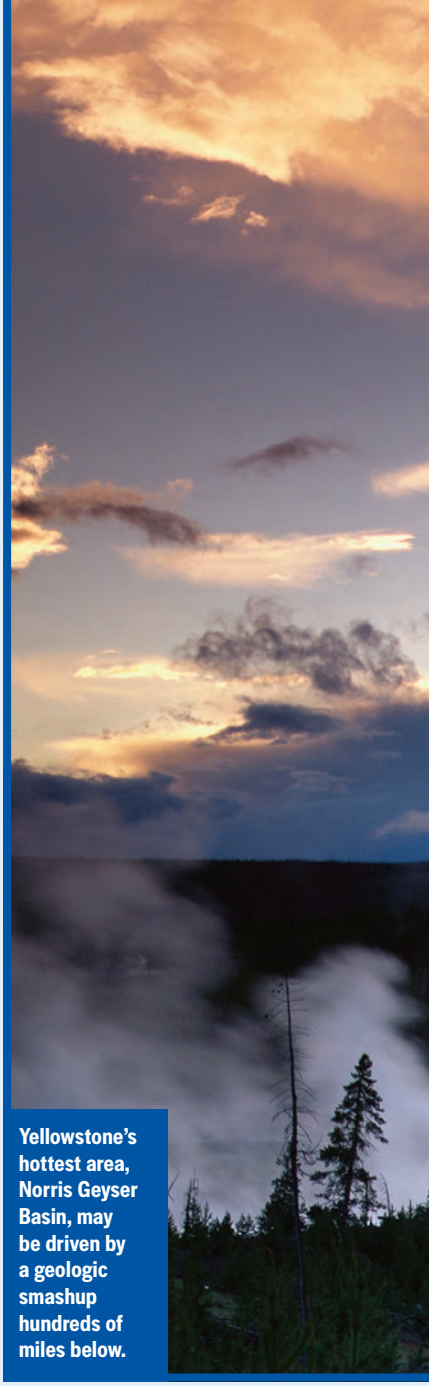
A Hubble Telescope Pointed Downward

The epic Transportable Array survey is the work of the Incorporated Research Institutions for Seismology, or IRIS, a consortium of more than 100 universities. IRIS president David Simpson and colleagues first conceived of the array in 1993. "The Hubble telescope had just gotten going," Simpson says, "and everyone was talking about what the next big project should be." Seismologist Guust Nolet suggested a giant, inward-looking seismic telescope to survey our own world, and the idea took off. In 1999 the National Science Foundation agreed to provide $91 million in funding. Starting in California, where the project could take advantage of existing seismic stations, students at IRIS-affiliated universities fanned out to get permission from landowners to install sensors on their property. The explosion of cellular communications in the early 2000s then eased a logistical hurdle by supplying a nationwide network that could transmit IRIS survey data in real time.

Although the Transportable Array does not create pictures in the conventional sense, it is providing amazing vistas of the Earth's interior all the same. Matt Fouch, a geophysicist at the Carnegie Institution for Science in Washington, D.C., says that for decades scientists have struggled to make sense of the jumbled geology of the Pacific Northwest, the land of the soaring Cascade range and the explosive Mount Saint Helens. But without being able to peek at a big picture that puts everything in context, "you can't know how the parts fit together," he says.

One puzzle in the Northwest is the Yellowstone hot spot, a 300-mile-wide region dotted with thousands of seething geysers and vents. Since the 1970s, prevailing opinion has held that Yellowstone's activity is driven by a giant plume of hot material rising up from the mantle, the thick middle layer of Earth's interior. But new images from the Transportable Array are calling that idea into question.

Where researchers expected to find a large mantle plume, the map of the geologic structure beneath Yellowstone instead seems to show a ghostly fragment of an old tectonic plate—a former chunk of Earth's rocky shell—lodged under the western United States, right near the Yellowstone hot spot. The fragment is one of many that probably broke off from an ancient section of crust called the Farallon plate, which began forcing its way under North America, moving from west to east, more than 200 million years ago—around the dawn of the dinosaurs. Fouch thinks Yellowstone's restless activity is driven not by a giant mantle plume but rather by mantle material being pushed around the edge of the stranded Farallon fragment. Not all of his col-



Yellowstone's hottest area, Norris Geyser Basin, may be driven by a geologic smashup hundreds of miles below.

TIM FITZHARRIS/MINDEN PICTURES

leagues agree, but "we finally have the whole picture," he says, "so we can argue meaningfully about what it means."

Is the East Coast Headed for a Crack-Up?

Engineers continuously relocate Transportable Array stations, leapfrogging sensors from the array's trailing western edge ahead to the eastern front line. As the project marches to the coast over the coming months, it may shed light on another long-standing mystery. Beneath the eastern United States, scientists have observed an area where seismic waves travel more slowly than expected. Suzan van der Lee, a geophysicist at Northwestern University, thinks the slowdown might be due to water released by another fragment of the Farallon plate. If so, she suspects that the liquid could eventually weaken the crust beneath the Atlantic Ocean near the continent's edge, causing it to break off from North America and sink back into the mantle. Within a few tens of millions of years, that process could make the East Coast as geologically active as the West Coast is today.

Van der Lee will have to wait for the Transportable Array survey to be complete—which should happen around 2015—to put her theory to the test. But after a long wait, real answers could be at hand. "For all the hypotheses proposed over the last two decades," Fouch says, "we'll finally be able to start figuring out which were right and which were wrong."

On the alpaca farm, Lashway—who works for Honeywell, the company contracted to install and maintain the array's sensors—is doing his bit to make that happen. "Take your last look," he says as he prepares to bury the station in sand. "It won't see the light of day for two years." In the meantime, though, it'll be in touch.

Emily Elert is a freelance journalist and a coauthor of *Global Weirdness*, a book from the foundation Climate Central, published in July.

BY SEAN CARROLL

Digging Up the Early Universe

Cosmologists are uncovering relics from the dawn of time, letting them look back almost all the way to the Big Bang.

RECONSTRUCTING ANCIENT history is not easy to do. Just ask a paleontologist: No matter how many dinosaur skeletons or Neanderthal skulls scientists dig up, they still can tell only a small part of the story of what life on Earth was like millions, or even thousands, of years ago.

Which makes it particularly amazing that over the last half-century, cosmologists (and I'm happy to count myself among them) have reconstructed the history of the entire universe all the way back to seconds after the Big Bang that sparked it into existence 13.7 billion years ago. And it is not just a rough reconstruction. We know exactly what the infant universe was made of and what it looked like in those earliest moments.

That's pretty impressive detective work, but we are still not satisfied. Now the push is on to peer back even farther, to a tiny fraction of a second after the Big Bang. This will help us address the deepest questions about our place in the cosmos: How did it all begin? Is our universe the only one? And if not, why this universe rather than some other one?

Distant Light of the Past

Studying the universe's past presents a challenge similar to studying the Earth of long ago: Over time, things change. For living things, flesh decomposes and bone turns into fossil. For cosmic things, many particles that came out of the Big Bang—such as electrons, protons, and neutrons—have been processed in the cores of stars. The trick to understanding the past is finding artifacts that have remained largely intact over vast spans of time. In this area, cosmologists are much more fortunate than paleontologists, because the universe harbors many particles whose identities have remained unchanged for billions of years.

The most obvious of these relics are particles of light, or photons. When we view an image of a stunning galaxy from the Hubble Space Telescope, we are actually looking at a snapshot of history. If the galaxy is 2 million light-years away, then we are viewing it as it was 2 million years ago because that is how long the light traveled, undisturbed through vast stretches of empty space, before it reached us. Over the last few years, Hubble has given us views of infant galaxies as they were just 500 million years after the Big Bang, allowing cosmologists to see how quickly the raw materials from the newborn universe coalesced into stars and then galaxies and then clusters of galaxies.

The most valuable photons are even older, dating back to only 380,000 years after the Big Bang. Before that time, the universe was an opaque fog, so hot and dense that photons could not travel very far before bumping into other particles and changing direction. But then the universe cooled sufficiently for electrons to stick to nuclei and form stable atoms. The resulting gas—almost all hydrogen and helium—was transparent, allowing photons to zip freely through space at last.

Many of those photons have traveled undisturbed ever since, and in 1964 a bunch of them landed on a radio antenna set up by Arno Penzias and Robert Wilson at Bell Labs in New Jersey. They had accidentally discovered the cosmic microwave background, the afterglow of the Big Bang.

In the years since, satellites such as Planck and the Wilkinson Microwave Anisotropy Probe have mapped these photons and provided a fantastic view of the 380,000-year-old universe. By studying subtle fluctuations in the temperature of the cosmic microwave background, cosmologists have determined the total amount of energy in the universe and how the form it takes has changed over time. Matter (both ordinary atoms and the invisible stuff called dark matter) once dominated the universe, but today it constitutes only a quarter of the content of the cosmos. The rest is a strange, anti-gravity substance known simply as dark energy.

Probing the Nuclear Inferno

The cosmic microwave background is a powerful tool, but cosmologists can call on even older relics, ones that penetrate the opaque, photon-trapping fog and bring us all the way back to the first seconds of the universe's history. Those relics are atomic nuclei, forged in the primordial fires of the Big Bang.

In 1948, George Washington University graduate student Ralph Alpher and his adviser, physicist George Gamow, theorized that over the course of its first few minutes, the universe was so hot and dense that it behaved like a nuclear fusion reactor, cooking the primordial soup of protons and neutrons into heavier atomic nuclei: deuterium or "heavy hydrogen" (one proton and one neutron), helium (two and two), and lithium (three and four). Their theory, known as Big Bang Nucleosynthesis, included detailed predictions of how

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much of each element would have been produced in the roughly three minutes of nuclear reactions.

Amazingly, we can test the Big Bang Nucleosynthesis theory by finding the primordial deuterium, helium, and lithium that remain today. Just as paleontologists hunt for fossils in isolated caves and dry rift valleys, cosmologists have identified relatively untarnished parts of the universe where atomic nuclei have remained largely undisturbed since the earliest times. Important targets are dwarf galaxies like I Zwicky 18, where stars did not ignite until recently, leaving most of the galaxy's material intact. Deuterium, helium, and lithium nuclei each absorb and emit light in a unique way, allowing scientists to point telescopes at I Zwicky 18 and determine the abundances of ancient nuclei very accurately. The observed amounts of these elements are just what Alpher and Gamow's theory predicts.

Think about what that means: Sitting here on Earth, cosmologists extrapolated our understanding back 13.7 billion years, to a few seconds after the universe began. We used that understanding to make predictions about the current universe—and we were right. We may not know for sure whether it will rain tomorrow, but we do know exactly how protons and neutrons bounced around like Super Balls in the nuclear inferno of the Big Bang. This will surely go down as one of the most impressive accomplishments of the human intellect.

And yet cosmologists want to do better still. The goal is to discover relics that predate even Big Bang Nucleosynthesis. At the moment that's not quite possible, but there is one promising candidate: dark matter, the dense but unseen stuff that holds galaxies together.

Artifact or Worthless WIMP?

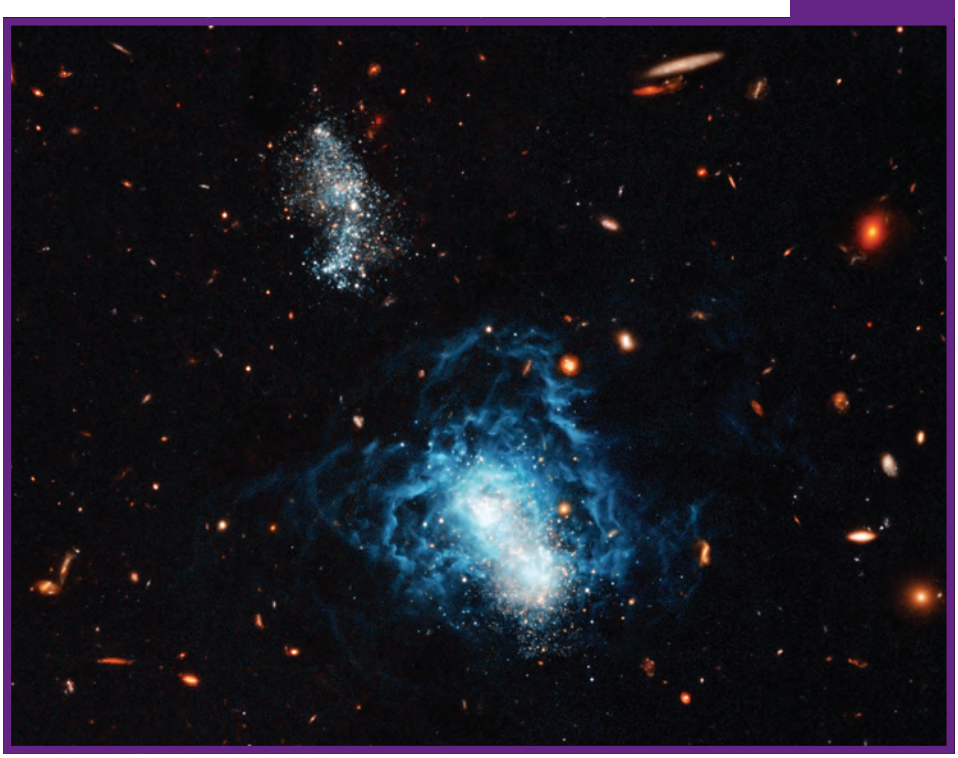
At first, dark matter may seem a strange choice. We have never directly detected it, and we do not know what it is made of. But we do know that it doesn't seem to interact very much with anything—which, for the cosmic paleontologist, is a great asset. (The lack of interaction is why dark matter is dark: Light has no effect on it.) According to leading theoretical models, dark matter stopped interacting with the rest of the primordial particle soup very early on, about 1/10,000 of a second after the Big Bang, when the temperature of the universe was over 100 trillion degrees Fahrenheit (today it averages –455°F).

Theorists' leading candidate for dark matter is the weakly interacting massive particle, or WIMP. Experiments in deep underground facilities, like the Soudan mine in Minnesota and the Gran Sasso laboratory in Italy, are searching carefully for WIMPs. At the same time, physicists are trying to create WIMPs directly at particle accelerators like the Large Hadron Collider near Geneva.

If these efforts succeed, we can measure the properties of WIMPs and then play the Big Bang Nucleosynthesis game all over again, this time with dark matter. We could predict precisely how much dark matter would be left over from the early universe and compare it with the amount we measure today. Then there are two possibilities: Either the prediction matches reality, and we can rightfully claim to understand what the universe was doing a scant fraction of second after it began; or the prediction fails, and we have to develop new, deeper theories to address the error.

Even if dark matter fulfills cosmologists' wildest dreams, our quest will be far from over. It may sound good enough to get to within 1/10,000 of a second after the Big Bang, but theorists believe a lot of interesting things happened before then, most notably a rapid expansion of the universe, called inflation, and of course the instant of the Big Bang itself—the equivalent of tracing evolution all the way back to the origin of life.

The closer we get to that point, the better we will understand how our universe came to be, and whether other universes could have formed in the same manner. One way or another, we will keep coming closer to understanding the very beginning of time.



Dwarf galaxies like I Zwicky 18 (bottom center) contain large quantities of matter that formed mere seconds after the Big Bang.

COURTESY NASA/ESA/A. ALOISI/STSCI

Aging Brain

CONTINUED FROM PAGE 50

into long-term storage. That's why, if you are over 50, you are more likely to remember the lyrics to a Beatles song than to any song you have heard in the past 20 years. To put this another way, our ability to learn new things is extraordinary when we are young and peaks in our teens. We can learn after that, but it becomes increasingly difficult. In an early study by psychologist Jeanne Gilbert, English speakers of different ages were asked to learn Turkish vocabulary words. People in their sixties learned 60 percent fewer words than young adults in their twenties who spent equal time and effort on the task.

One of the most frustrating experiences we have as we age is accessing a particular word from long-term memory—the so-called "word-finding" or "tip-of-the-tongue" problem. Deborah Burke, a psychology professor at Pomona College who has studied this phenomenon for more than 20 years, explains that old people suffer from a disconnect between the meaning of a word—which presumably tells you that it is the correct word to say right now—and the sound of that word. It is, she says, "the most irritating and disturbing cognitive problem" reported by older adults. We do not know what causes the disconnect.

4. Intelligence

We also get dumber as we age. IQ remains fairly stable, but that is because it is a relative measure—a quotient (the Q) that shows where we stand relative to people our own age. The problem is that raw scores on intelligence tests actually peak in our teens, remain high for a few years, and then decline throughout life; IQ remains fairly stable only because people decline at roughly the same rate. And yes, even geniuses decline. I recently asked Nobel Laureate James Watson, 84, when he reached his intellectual peak, and he replied, "Twenty, maybe 21—certainly before we found the DNA structure." That seminal work had been done when he was 25.

Intelligence, like memory, is divided into types that decline somewhat differently. Factual information is the basis of what is called crystallized intelligence, and much of the crystallized knowledge we acquire stays fairly strong at least into our sixties. However, fluid intelligence—our ability to reason—declines dramatically in most people, in large part because we get *slow*. Generally speaking, on tasks involving reasoning, what a 20-year-old can do in about half a second takes a healthy 80-year-old more than two seconds—if, that is, he or she can do it at all. As Douglas Powell of the Harvard Medical School puts it in his recent book, *The Aging Intellect*, "No other single mental ability declines as rapidly during the adult years as processing speed."

Neuroscientists tackle the decline in reasoning and working memory under an umbrella concept called executive function. Somewhere in the brain there seems to be a coach: a system or structure that schedules and prioritizes, garnering resources, redirecting attention, or switching tasks as needed. Adam Gazzaley, a neurology professor at the University of California, San Francisco, has conducted research documenting how that coaching ability declines as we age. For example, older people are bad at multitasking, Gazzaley says, because they have trouble redirecting attention back to a task after it has been interrupted. On average, people in their seventies generally require twice as much time to do two things at once as do young adults, and they also make more errors on the tasks. That inability to focus takes its toll. "I would not be capable of doing groundbreaking work today," renowned physicist Freeman Dyson, 88, told me recently. When he was young, Dyson said, he could focus on a single problem nonstop for a week. "Today," he said, "I'm limited to two hours a day of serious work—which wouldn't be enough."

THE DETERIORATION OF THESE FOUR SYSTEMS appears to be an inevitable part of normal, healthy aging, although the rate of decline varies among individuals (see "How Some Brains Stay Razor Sharp," page 50). When you add disease to the picture, things truly look bleak. Half of Americans over 85 are suffering from Alzheimer's disease, which eventually robs people of their memories, identities, and the ability to function even minimally. Alzheimer's becomes increasingly common with age—so common that neurologist Gary Small of UCLA suggests that if we all lived to 110, we all would have it. These are the brutal truths we must face as we and our loved ones age.

Immortality

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organisms that already possess such attributes. Think of it as genetic data mining. We could get radiation-resistance genes, for example, from the *Bdelloid rotifer*, a class of small invertebrates that live in freshwater pools and survive megadoses of ionizing radiation. We will acquire other life-span-enhancing attributes by combining the best of all genomes of people who are comparatively youthful even though they are older than 100. The Church lab is currently analyzing the genomes of centenarians.

Semi-immortals could combine the best aspects of youthful dynamism with the wisdom of long experience. Such people in abundance would be of great benefit to society. If most of us expect to live possibly indefinitely in good health, there is a strong motivation to help protect humanity from long-term risks like extinction from a new pandemic, the exhaustion of key nonrenewable resources, global nuclear warfare—or a meteor strike. After all, the survival of Earth itself is a prerequisite for the survival of individuals, whether mortal or potentially immortal. One does not want to go to all the trouble of reaching for immortality only to be wiped out by a flying rock.

George Church is a professor of genetics at Harvard Medical School and director of the Center for Computational Genetics. **Ed Regis** is a science writer and author of seven popular science books.

20 THINGS YOU DIDN'T KNOW ABOUT CARS

By Corey S. Powell

1. In 1760 King George III housed around 30 horses in the Royal Mews stables in London. Today a typical compact car packs a 150-horsepower engine. So a suburban commuter has instant access to five times as much sheer muscle as the king who nearly crushed the American Revolution. **2.** By the formal definition of horsepower (the power required to lift 33,000 pounds by one foot in one minute), a real horse musters only 0.7 horsepower. **3.** Not only has the horse been outgunned by the car, it faces the further indignity of not being able to keep up with itself. **4.** Contrary to legend, Ford's Model T originally came in a variety of colors… and black was not one of them. The "any color so long as it is black" philosophy arrived in 1913, as Henry Ford sought to simplify production. **5.** Volkswagen had the good sense to change the original, Hitler-sanctioned name for its small car, the Kraft durch Freude Wagen ("Strength Through Joy Car"). You know it as the Beetle. **6.** The first documented auto fatality in the United States was H. H. Bliss of New York City, who was struck by an electric taxicab on September 13, 1899, while alighting from a trolley car. **7.** The motor vehicle fatality rate in the United States—the average number of deaths per passenger-mile of driving—has dropped by roughly 80 percent in the past half century. **8.** Last year 32,310 Americans died in auto accidents. If the 1962 fatality rate still held, there would be an extra 150,000 deaths annually, equivalent to losing the population of Pittsburgh every two years. **9.** Credit a mix of improvements, including crash impact standards, air bags, better tires, antilock brakes, and stability control. **10.** One of the biggest factors? Seat belts. 84 percent of people now buckle up, compared with 14 percent three decades ago. **11.** Please don't kick the tires. The contact patches—the areas of the tires that actually touch the road at any given moment—cover an area of just over 100 square inches for an average family sedan. **12.** In other words, all of the accelerating, cornering, braking, and everything else that your four wheels do, happens on a piece of ground scarcely bigger than your own two feet. **13.** Lighting is one of the next frontiers in safety. BMW is developing headlights that highlight nearby people to help focus the driver's attention, and a Carnegie Mellon University researcher has developed lights that can track droplets and avoid illuminating them, rendering rainfall nearly invisible. **14.** In 2004 Nevada hosted the first Darpa Grand Challenge for autonomous cars. None of the contenders finished the course, and one lunged menacingly at spectators. Now Google's fleet of self-driving cars has completed 140,000 miles on the road with only two small accidents—one of them caused by human error. **15.** Betting all-in on robots: This year Nevada became the first state to issue licenses for self-driving cars. **16.** Many high-end vehicles are already partly autonomous, with brakes that activate if sensors indicate an impending crash, steering that prevents drifting, sonar systems that navigate into parking spaces, and cruise control that prevents following the next car too closely. **17.** Self-driving cars could improve highway flow by regulating distances between cars and ease urban congestion by automating the search for parking (which causes up to three-quarters of city traffic). **18.** Could they even eliminate dumb driver errors? "Crashless is the goal," John Maddox of the National Highway Traffic Safety Administration recently told *Automotive News*. **19.** The AMC Gremlin, often cited as one of the ugliest cars ever made, pioneered the high-hood, sloping-side-window look ubiquitous among today's SUVs. Which makes AMC's Bob Nixon perhaps the world's most unsung designer. **20.** What is the most beautiful car? Good luck getting any two people to agree, but the 1946 Cisitalia 202 GT (left) was the first to be exhibited alongside the Picassos at New York's Museum of Modern Art. If it does not make your heart jump, check your pulse.

Corey S. Powell is the editor in chief of DISCOVER. He drives a pearl gray 1955 Sunbeam Alpine. In his dreams.

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