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Innovation

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The Inner Limits

By Chris Jozefowicz

Are computers approaching the furthest extent of their power?

"If you were living in the year 3,000 B.C.E., how much change would you see in your lifetime?" asks Doug Burger, a computer scientist at the Microsoft Corporation. "You probably wouldn't see any." Change happened very slowly in ancient times.

"In the 1700s or 1800s, change was measured in decades," Burger continues. "In the 20th century, it was measured in somewhere between decades and years. Now we're seeing things change in years to months." Faster, smaller computers, smart phones, and other electronic gadgets drive a continuing revolution in how people work and play.

Will that spectacular rate of change keep going into the future? Not in the same way, says Burger. As computer scientists continue to make the guts of electronic devices smaller and quicker, they've begun to push against some limits of what may be possible.

Tiny Switches

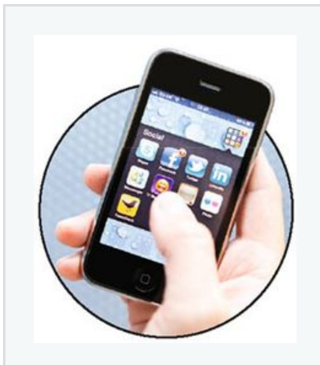
The part of a computer's guts that does all the computing is run by many tiny *transistors.* "Transistors are effectively like little light switches," Burger says. When a transistor is on, electricity flows through it. When it's off, the current stops.

A modern computer has hundreds of millions to billions of transistors packed together to form *integrated circuits,* or *computer chips.* Lightning-quick changes in the complex pattern of switches in the "on" and "off" positions enable a computer to do computations and store information in its memory. "For 40 years we've been making transistors smaller, smaller, and smaller," Burger says. They've become faster, too, while needing less energy. The results have been amazing. The latest smart phone is faster than a refrigerator-sized, 5-ton supercomputer from the 1970s. "It's been magical for us," Burger says.

Lagging Efficiency

Rapid change is still the norm for computer technology, but some rates of change are slowing. Scientists can pack more and more transistors onto chips, but computer chip *efficiency* is lagging. Efficiency is a measure of how something performs compared with how it might perform if its energy use were ideal.

Every tiny transistor wastes a little energy when it's on. That waste takes the form of heat created by the electric current flowing through the transistor. If you've touched a hot cellular phone or felt the warm air blowing out of a computer's vent, you've sensed the wasted energy.



iStock

Smart phones and tablets use computer chips that still have room to get faster. Such devices run on limited programs, so their chips aren't as complex as the ones found in PCs.

The rate of change in chip efficiency is slowing because designers are making less progress reducing how much energy transistors consume—and waste. If the newest chips were to consume all the energy they need to power every one of their transistors, they would get too hot. The chips' parts would melt and fuse. The computers would spit out incorrect results.

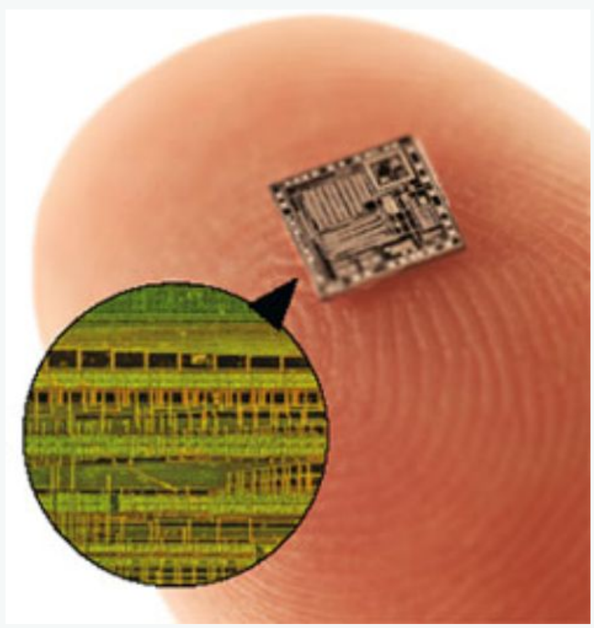
To prevent that from happening, some parts of the newest computer chips must remain off while other parts are on. Researchers call the unpowered parts *dark silicon.* (Silicon is the material that most transistors are made of.) When silicon is dark, a chip isn't working as hard as it could, however.

Burger and some colleagues in computer science have studied the problem of dark silicon. Their conclusion: The pace of computer innovation will slow in the coming decades. If computers were to continue evolving at the breakneck speed of the past 40 years, we might expect their performance to improve by at least 30 times by 2024. Burger's calculations suggest that we should expect a fraction of that improvement. "I think we're likely to see something between 3.7 times and 7.9 times," he says.

Twilight of the PC?

Burger's prediction hardly fazes David Patterson, a computer scientist at the University of California, Berkeley. "My position is that we need to innovate," he says.

One innovation is *multi-core processing.* Many of today's computers already have it. Their computer chips are effectively several chips linked together. Future designs might link even more chips to keep speeding things up. Each chip would be specialized to perform a certain function when needed.



Lucidio Studio Inc./Getty Images; Nick Botto/Getty Images

A computer chip. Left: A close-up of the intricate, microscopic circuitry on a computer chip

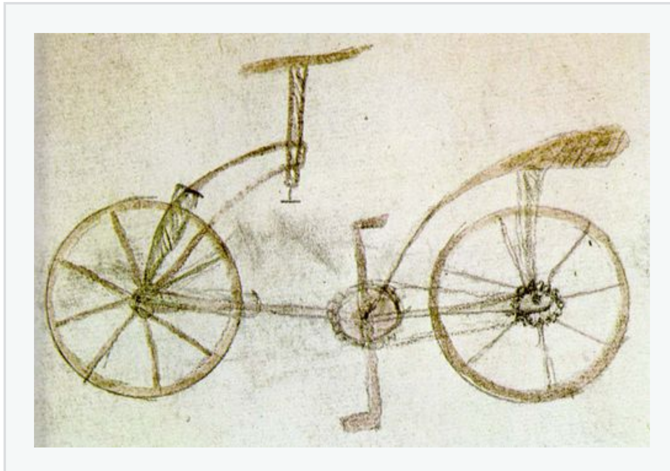
Patterson compares multi-core processing to having a car with many engines, each one designed for driving at a different speed or on a different road condition. Some parts remain off while the only parts needed are on. "It doesn't matter if silicon is dark or light," Patterson says. "What matters is if it can continue to deliver performance into the future."

Burger's predictions about dark silicon apply mostly to personal computers (PCs), adds Patterson. But consumers are increasingly turning away from PCs to smart phones and tablets for many of their computing needs. Those devices don't use the same kinds of chips PCs do. "Smart phones and tablets have room to get faster," Patterson says.

Patterson imagines a future in which people carry or even wear many small computers. Such devices might be slower than top-of-the-line PCs, but each one would have its own task. And the devices would communicate and work with one another in a network, almost like a multi-core processor. Researchers call that type of sharing *cloud computing.*

"This is such a fast-moving field," Patterson notes with optimism. "When you start talking about what's going to happen past 10 years, it's hard to worry."

New Vinci



Leonardo da Vinci's bicycle sketch, 1493

Smooth Shifting

Old ideas help power the newest bicycles.

Leonardo da Vinci never rode a bike. Bicycles didn't exist when he lived (1452—1519). But designs by da Vinci did inspire one of today's cutting edge bikes. Parts of the new bike follow sketches done by the artist and inventor in 1490.

What can today's bicycles gain from old da Vinci sketches? Bill Klehm says da Vinci's doodles were the inspiration to overcome some basic challenges of bike riding. "Have you ever had the chain fall off your bike?" Klehm asks. "Have you ever been stuck in the wrong gear and unable to climb a hill?"

Klehm is the president of Fallbrook Technologies. His company invented a new type of **transmission** for bikes. A transmission is a device that sends a vehicle's power to its wheels. The company named the new bike transmission NuVinci in honor of da Vinci.

Geared Up

The transmission in a traditional bike is a system of **gears**. Gears are sets of wheels with interlocking spikes. A chain connects gears on the pedals to gears on the wheel.

When you shift the gears on your bike, you move the bike chain between gears of different sizes. A large gear on the pedals and a small gear on the wheel make the bike travel a long way with each turn of the pedal. However, going uphill is hard. Shifting to larger gears in back and smaller pedal gears makes pedaling easier, but the bike doesn't go as fast.

Early bikes had just one gear. Top bikes today let riders choose between 24 gears. Not bad, Klehm says—but there's room for improvement. Switching the chain between gears can make pedaling hard. Sometimes the chain falls off.

On the Ball

Fallbrook's new bike transmission, called a **continuously variable transmission** (CVT), doesn't have those problems. In fact, it doesn't have traditional gears at all. It uses a system of rotating balls. The balls transmit the power from the chain to the wheel. The position of the balls determines how much each turn of the pedal moves the wheel. Unlike shifting conventional gears, changing the position of the balls goes very smoothly. "There's no clicking between gears," Klehm explains.

So far, more than 15,000 bikes with the NuVinci have hit the streets. In 2008, Klehm said, the company expects to sell 80,000 more. Bike gears soon might go out of style, just as huge front tires did 120 years ago. If gears go, expect learning to use the new transmission to be simple. As Klehm says, "You adjust until it feels good ... and you're where you need to be."

Double Vision

By Chris Jozefowicz

How 3-D TVs use powerful tricks to add depth to the small screen

Blue lasers are shooting past me. Confetti is swirling in front of my eyes. The Black Eyed Peas are singing and dancing onstage. They seem close enough that I could reach out and touch them. I try, but I grab only handfuls of air.

I'm not really at a Black Eyed Peas concert. I'm in a Best Buy store, watching a concert on a new three-dimensional (3-D) television.

The 3-D effect is amazing, much better in some ways than what you see in movie theaters. "The closer we get to creating a natural perception environment, the more you feel like you're in a scene," says Brian Schowengerdt, a scientist who studies 3-D display technology at the University of Washington. But even the newest 3-D TVs fall short of capturing what our eyes and brains do every day.

Optical Illusions

You may be surprised to learn that the human eye can't see in 3-D. "We only have access to 2-D images," says Schowengerdt. "It's the job of the brain to interpret a host of cues to determine depth and create a 3-D image."

The most powerful cue is *stereopsis*, says Schowengerdt. Stereopsis is the way your two eyes create a sense of depth by working together. Your eyes look at the same scene from slightly different angles. The brain compares the different image from each eye and combines the images to create a sense of depth—of three dimensions.

From the first 3-D movies in the 1920s through today's cutting-edge TVs, the goal has always been the same: find a way to project a different image to each eye. The first 3-D movies, which required viewers to wear eyeglasses with one red lens and one blue lens, used *anaglyph technology.* Side-by-side projectors projected two versions of the same movie onto the screen, one version in red, the other in blue. The red lens in the glasses blocked the light from the red image, and the blue lens blocked the light from the blue image. So each eye saw a different image, and the brain combined them to create the illusion of depth.

New 3-D movies, such as *Avatar* and *Toy Story 3*, use *polarized light* to direct a separate image to each eye. Light is normally a collection of waves vibrating in many directions. When light is polarized, all the waves vibrate in the same direction.

Movies using polarized light also employ two images on the same screen. One image is polarized in one direction; the other, in a different direction. Glasses with polarized lenses allow only light waves vibrating in a certain direction to reach each eye.

Flickering Lights

Most 3-D TVs use the *frame sequential method* to create a 3-D effect. You still need special eyeglasses, which are a bit bulky because they require batteries. The electricity quickly changes the two lenses from clear to dark.

The lenses change very rapidly. When one lens is clear, the other is dark. They flip back and forth between light and dark more than 100 times a second—so fast, in fact, that each lens looks gray. Those flippings are synchronized with the TV, which rapidly flashes between two different images. The TV and the glasses work together. When the TV flashes the image meant for the right eye, the right lens is clear and the left lens is dark. Then the TV flashes the image meant for the left eye, and the glasses switch so the left lens is clear.

Those changes are so quick that your brain doesn't consciously notice. It processes the images to create a smooth 3-D scene. "The brain is sensitive to flicker," Schowengerdt says, "but once you have more than around 60 flashes per second people tend not to see flicker." The TVs I saw could flash up to 240 images per second.

Restricted View

"Three-D TV does a good job of creating a sense of depth," says Schowengerdt. That was my impression too. The 3-D effect was strong and seemed brighter than it is in 3-D movies, which look too dark to me.

That doesn't mean the system is perfect. I noticed one very odd thing about 3-D TV. As much as the Black Eyed Peas—or the soccer players or the polar bears or any of the other things I watched—appeared to be in the room with me, they looked comically tiny, like animated dolls.

That problem "underscores how hard it is to create really good 3-D content," says Schowengerdt. Filmmakers may be able to control stereopsis, but they often mess up a bunch of other visual cues that we need to see depth.

I wasn't alone in my reaction. A man watched the concert next to me at Best Buy. After a minute, he took off his glasses and said, "They say movies make things look larger than life. This makes them look smaller than life."

How 3-D TV Works

You see the world in three dimensions because you have two eyes set slightly apart, each one taking in a slightly different image of the world. Your brain puts those two images together to form a 3-D view. Three-D TV works in much the same way, enabling the eyes to see what's happening on the screen from two different perspectives.

B. Vander Heyden; Image from Walt Disney Pictures

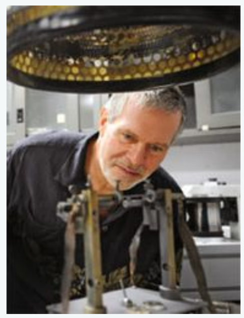
All movies and TV shows are a stream of thousands of images flashed on the screen. On a 3-D TV, each image appears in two versions. The first version of the image (Image A) can be seen through only one lens of the 3-D eyeglasses that each TV watcher wears. The second first version of the image (Image B) can be seen only through the other lens of the eyeglasses. The viewer's brain puts the two versions together to form a 3-D view. The next set of two images then appears one after another. The process repeats itself for thousands of pairs of images.

First Life

By Kirsten Weir

How did Earth's earliest life-forms evolve out of ancient raw materials?

Robert Hazen builds bombs. He's not a weapons manufacturer or a criminal, though. He's a scientist at the Carnegie Institution for Science in Washington, D.C.



© Amanda Lucidon/Lucid Pix

Robert Hazen looks into the pressure bomb that he uses to simulate the chemical environment that might have given rise to life on Earth.

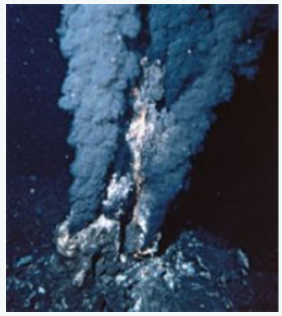
Hazen uses small metal cylinders called pressure bombs to blast minerals with insanely high pressures and temperatures. It's all done in the hopes of answering one of the biggest questions in science: How did life begin on Earth?

Hazen's background is studying *minerals*—solid, crystalline materials that form naturally through geological processes and make up rocks. He's using that knowledge to figure out how ancient minerals might have been involved in the evolution of the first primitive life-forms.

Back-In-Time Capsule

Earth's first life-forms, says Hazen, could have arisen almost anywhere on the planet—at least any place where there is *energy.* Energy is the capacity to do work, and all living things need it to function.

Solar energy bathes Earth's surface. Chemical energy from rocks and minerals pulses beneath Earth's crust. At the bottom of the oceans, heat energy flows from *hydrothermal vents.* Hydrothermal vents are cracks in the seafloor where superheated, mineral-rich water gushes upward. The undersea hot springs are homes to bizarre life-forms that exist nowhere else.



Ralph White/Corbis

A hydrothermal vent

As an expert in minerals, Hazen is intrigued by the mineral-rich worlds around deep-sea vents. Did ancient hydrothermal vents spawn the first living things? To test that idea, he dropped the bomb.

First, he combined a few basic ingredients that were present during Earth's early days: carbon, water, and several other simple compounds. Next, he put the ingredients in a pressure bomb to recreate the conditions around hydrothermal vents. Then, he cranked up the heat to a scorching 249 degrees Celsius (480 degrees Fahrenheit) and squeezed the contents to a pressure 2,000 times greater than atmospheric pressure at sea level. "We let those high-temperature, high-pressure conditions work their magic," he says.

After a few hours, he cracked open his back-in-time capsule. Inside he found thousands of newly made compounds, including many *organic* ones. Organic compounds contain one or more carbon atoms. All life is based on them. The most interesting organic compounds that Hazen found were simple sugars, amino acids, and lipids. Those three materials are necessary for life as we know it. "Depending on the conditions and what minerals you use," Hazen notes, "you can make all the building blocks of life."

Getting Together

Hazen's research showed that the unique conditions around hydrothermal vents could have created the basic ingredients of living things. But how, in the vast ocean, did a handful of new molecules and compounds get together to form the more complex chemicals that led to life? That's the question Hazen is working on now.

Some molecules seek one another naturally, he says. Lipids are one example. A lipid molecule is long and skinny. One end is naturally attracted to water, and the other end is repelled by it. When lipids are underwater, they bunch together to form a little ball. Their water-loving heads face outward, giving them contact with the fluid. Their water-hating tails poke into the center of the ball, away from the wet stuff. Simply because of their chemical properties, Hazen says, "they self-assemble into spherical structures that look like little cells."

Other organic molecules like to cling to the surface of certain minerals. Life's earliest molecules might have been attracted to rocks and minerals on the ocean floor. Once they began meeting up on those surfaces in large numbers, they could have joined together to create bigger molecules and, eventually, the first living things on the planet.

Hazen's research doesn't apply just to life on Earth. Scientists have found amino acids and other molecular building blocks of life inside space rocks. What happened here might be happening on moons and planets throughout the universe, he says.

Earth First

For now, Hazen is concentrating his efforts here on Earth, trying to work out how young, organic molecules might have found one another in the big, lonely ocean. In other labs across the country, scientists are looking at how those molecules might have joined together and started copying themselves.

The researchers are all inspired by a common goal. "One of the great human motivations, in science and the arts, is to understand who we are and where we came from," Hazen says. "Studying the origin of life is part of that exploration—it's part of what it is to be human."

Life's Building Blocks

Robert Hazen's pressure-bomb experiments created a number of organic molecules, including simple sugars, amino acids, and lipids—the main building blocks of life. All three are found in every living organism on Earth.

- **Simple sugars** are relatively small molecules that contain carbon, hydrogen, and oxygen. *Carbohydrates* are made from simple sugars. Carbohydrates provide structure to cells and are an essential component of DNA. They also provide energy to living things.

- **Amino acids** are compounds that contain carbon, hydrogen, oxygen, and nitrogen. *Proteins* are made from amino acids. Proteins are complex substances that perform many crucial jobs in living organisms, such as transporting oxygen in the blood and controlling chemical reactions inside cells.
- **Lipids** are a group of fatty molecules that contain carbon, hydrogen, and oxygen. *Cell membranes* are made from lipids. Cell membranes are the barriers that surround living cells and *organelles,* the specialized structures inside cells.

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Ice Picks

By Kirsten Weir

A new telescope is buried more than a mile beneath the Antarctic ice.

When physicist Jim Madsen goes to work in Antarctica during the South Pole summer, he enjoys sunlight 24-7. That's ironic because his project, a giant telescope called IceCube, requires total darkness. But the round-the-clock sunshine doesn't affect IceCube, because it's located deep within the Antarctic ice. "You don't have to get very far beneath the surface," says Madsen, a professor at the University of Wisconsin, River Falls, "and it's pitch-black."

IceCube was designed to detect tiny invisible particles from space. "We have these particles that we think are the most abundant in the universe, but they're almost impossible to detect," he says. Almost ... but not quite. The IceCube team—hundreds of scientists from more than 30 countries—has figured out that the ice-covered continent is a perfect place to detect the particles. With luck, the invisible cosmic messengers might offer clues to some of the biggest mysteries of the universe.

Haley Buffman/NSF & Jamie Yang/NSF

Spread over a cubic kilometer of ice in Antarctica, IceCube is the largest neutrino detector in the world. The colored dots on this aerial view of the site indicate where long cables are suspended inside deep holes in the ice.

Blue Glow

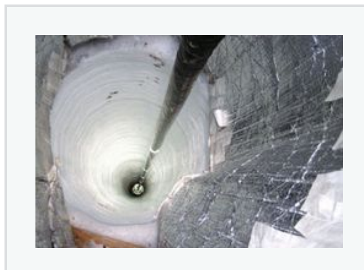
IceCube isn't your typical telescope. It doesn't reveal details of Pluto's surface or take beautiful snapshots of distant galaxies. It doesn't even point toward the sky.

IceCube detects *neutrinos.* Neutrinos are some of the smallest particles in the universe—tinier even than atoms. They're invisible, have hardly any mass and no electric charge, and interact very weakly with other particles.

Because of those properties, neutrinos zip easily around space. A neutrino can travel billions of miles through the cosmos, passing right through planets as it goes. Trillions of neutrinos are speeding through your body at this very moment.

Neutrinos are very hard to detect, says Madsen. To sense their presence, complete darkness and a large expanse of something clear are essential. Antarctica's deep, clear ice fits the bill perfectly.

IceCube is made up of more than 5,000 basketball-sized detectors called *digital optical modules* (*DOMs*). They're arranged on long cables, like beads on a string, with each cable suspended vertically inside a deep hole in the ice. Altogether 86 strings are suspended inside holes that extend as far as 2.4 kilometers (1.5 miles) below the surface.



NSF/B. Gudbjartsson

Most neutrinos zoom through ice unimpeded and undetected. Occasionally, though, one bumps into an ice molecule. When that happens, a *muon* is created. A muon, like a neutrino, is an *elementary particle*—a particle that can't be broken down into smaller particles.

When a muon speeds through ice, it generates a blue glow called *Cherenkov radiation*. Antarctic ice is so clean and clear that the DOMs can pick up that glow from a good distance, says Thomas Gaisser, a physicist at the University of Delaware. "You can see the light from 100 to 200 meters [328 to 656 feet] through the ice," he says.

The DOMs record data about every neutrino hit, enabling the scientists to see what direction the neutrinos came from and how much energy they carried. "The idea is to use neutrinos to learn about the universe," Madsen says.

John Jacobsen/NSF

Scientists string a digital optical module on a cable.

Mystery Matter

Neutrinos are released by high-energy events. Some neutrinos are created on Earth by the nuclear reactions in nuclear power plants. Some are created when *cosmic rays* (high-energy, charged particles from space) collide with atoms in the atmosphere. Others are created in the sun.

The IceCube scientists aren't focusing on neutrinos that emerge from those sources. They're hunting for neutrinos from distant, violent events such as *supernovas* or *gamma-ray bursts*. A supernova is the death explosion of a massive star. A gamma-ray burst is a giant explosion that releases a blast of high-frequency electromagnetic radiation. Gamma-ray bursts occur once or twice a day somewhere in the universe.

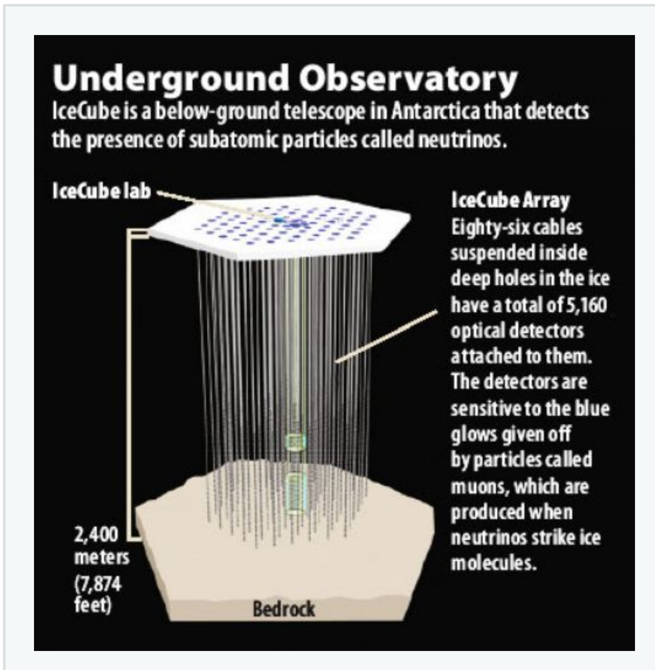
What triggers those outbursts? Researchers have no idea, but IceCube might help them find out. "If there are neutrinos coming from gamma rays," says Madsen, "[IceCube] will tell us something about what could be producing all that energy."

IceCube might also help scientists understand *dark matter*. Dark matter is something believed to make up most of the matter in the universe. No one has ever seen it directly or figured out exactly what it is, however. But if dark matter is out there, then an opposing type of matter, called *anti–dark matter*, must be too.

When dark matter and anti–dark matter come together, says Madsen, they should obliterate each other, creating high-energy neutrinos. If IceCube can find those extra energetic neutrinos, it could help scientists determine dark matter's identity.

After seven years of construction, IceCube was completed a year ago. Researchers have now started poring over the data it has churned out so far. It's too soon, though, to say exactly what the telescope has found. The scientists are still figuring out how to identify which neutrinos are created in Earth's atmosphere and which ones come from space. "That's the tricky part," says Madsen.

"Up until now, nobody has had a telescope large enough that you could get this information," he says. "We're hoping we'll find something brand-new."



Danielle Vevea/NSF & Jamie Yang/NSF

Perfect Fit

By Kirsten Weir

Doctors learn how to transplant organs without the worries of rejection.

Demi-Lee Brennan isn't the girl she used to be. After receiving a new liver when she was nine years old, her body underwent an astonishing transformation. Her blood type and her immune cells changed to match those of her liver donor. In a medical first, the Australian girl had acquired her donor's immune system.

Even before Demi's story came to light in the winter of 2007, U.S. researchers had been trying to encourage the immune systems of transplant patients to do what Demi's did on its own. In January 2008, a team of scientists and surgeons at Massachusetts General Hospital in Boston announced that it had pulled off the trick. The team's new technique could improve the lives of the nearly 30,000 Americans who receive organ transplants each year.

Resisting an Army

Demi's tale began when she was nine years old and became seriously ill. Doctors determined that an unknown virus was attacking her liver. Surgeons performed a transplant, replacing her failing liver with a healthy one taken from a boy who had recently died. The surgery saved her life.

The biggest challenge to any transplant's success is usually the patient's own *immune system*. The immune system protects the body from foreign cells such as bacteria and viruses. To do that, it employs an army of *white blood cells*, some of which keep watch for foreign invaders while others attack and destroy them.

Unfortunately, white blood cells identify transplanted organs as foreign entities and attack them the way they would viruses and bacteria. To prevent such attacks, transplant patients are prescribed *immunosuppressant drugs*. The drugs damp down the immune system, keeping the white blood cell soldiers in check.

Demi began taking immunosuppressant drugs immediately after her transplant. Several months later, though, her doctors made a startling discovery. Before her transplant, Demi had type O-negative blood. Now, her blood was O-positive—the blood type of the boy whose liver she had received. All of Demi's blood cells, including the white cells, had changed to match those of her organ donor.

What had happened? *Stem cells* in the transplanted liver had made their way into Demi's *bone marrow*. Stem cells are immature cells that have the ability to mature into many different kinds of adult cells. Bone marrow is the spongy tissue in the center of the bones that produces new blood cells, including immune cells. Inside Demi's bones, stem cells from the donated liver began churning out new blood cells. Eventually they replaced her native cells.

Demi's new immune system identified the transplanted liver as part of her own body, rather than a foreign invader. Her liver became safe from an immune attack. She was able to stop taking immunosuppressant drugs.

Tricking the System

The immunosuppressant drugs had made transplants possible, said David Sachs, director of the Massachusetts General Hospital Transplantation Biology Research Center. "The drugs have saved many lives," he noted. Yet the drugs weren't perfect. After all, they weakened the body's defense system. Although that weakened state protected transplanted organs, it also put patients at risk for infections and some types of cancer, he said. Worse, half of all transplanted organs were rejected within 10 years, even with immunosuppressant drugs.

By 2008, Sachs and his colleagues developed a new technique to prevent organ rejection. They tested it on five kidney transplant patients. Each patient received a kidney plus a bone marrow transplant from his or her kidney donor. After the procedure, Sachs says, the donors' bone marrow cells mixed with each patient's own cells. The patients took on a kind of hybrid immune system—a condition known as *mixed chimerism*.

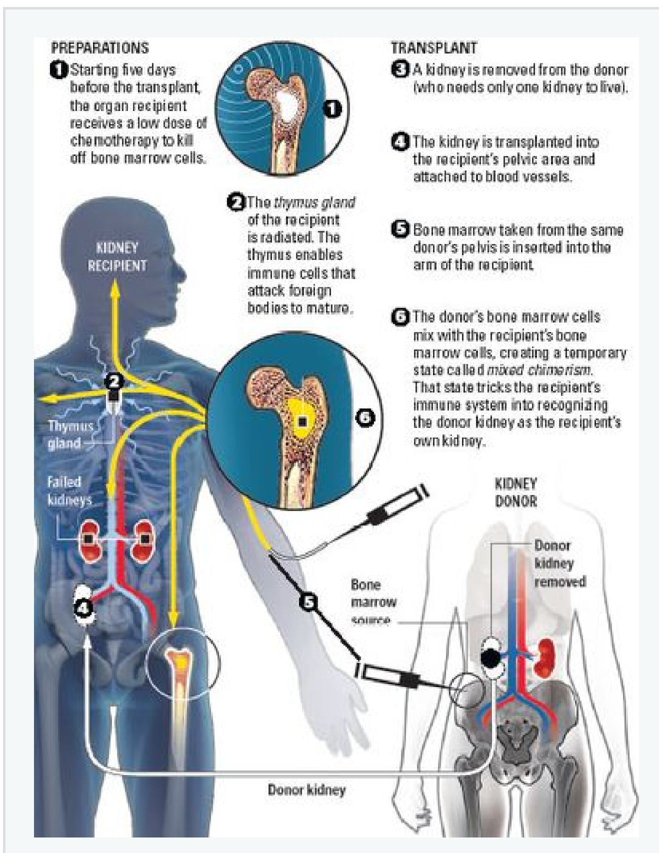
The result was similar to Demi's case, though not exactly the same. "She became a complete chimera," Sachs explained, wholly taking on her donor's immune system. Sachs's mixed chimeras, on the other hand, retained their own immune cells in addition to those of their donors.

Sachs's patients remained mixed chimeras for only a few weeks. Then their original immune systems took over. Still, that was long enough to trick the patients' immune systems into tolerating the transplanted kidneys indefinitely. "Even though chimerism disappears," Sachs said, "[the patients' bodies] don't reject their organs." One patient experienced complications, but the other four were able to stop taking immunosuppressant drugs. A checkup in 2008 showed that the patients were doing well, two to five years following their transplants.

The next step for Sachs and his team was to involve testing the technique on other types of organ transplants. "I hope this will improve the quality of life for [transplant] patients," he said.

Trick Transplant

By performing double transplants, doctors at Massachusetts General Hospital were able to keep their patients' immune systems from rejecting transplanted kidneys.



James Abundis/Globe Staff; Source: Dr. David H. Sachs; New England Journal of Medicine

Super Bowl

By Pearl Tesler

Is technology taking the challenge out of competitive bowling?

Bowling pins: Lawrence Manning/Corbis; Flag: Getty Images

"Have you shot a 300?"

Among serious bowlers, that's *the* question. Scoring a 300 in bowling is the ultimate dream—12 strikes in a row, the perfect game. It's like pitching a no-hitter in baseball.

Michael and Darren Tang, brothers 13 and 16 years old from San Francisco, can each answer yes to the 300 question. Michael bowled his first perfect game when he was just 10 years old.

Courtesy of the Tang family

Not long ago, the idea of a 10-year-old bowling a 300 game would have been laughable. A perfect bowling game used to be rare; in 1970, nonprofessional bowlers in the United States bowled 854 perfect games. Today, scores of 300 are much more common; last year, nonprofessionals bowled more than 52,000 perfect games. What accounts for that staggering increase? Technology.

Invisible Tech

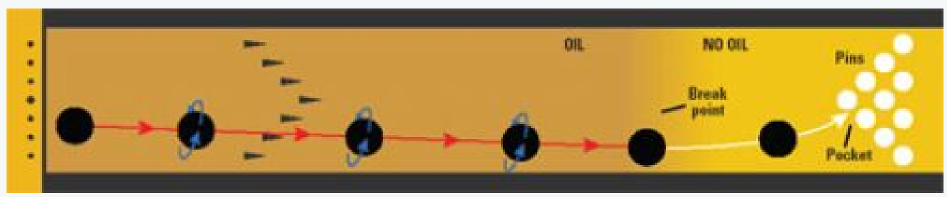
Step into your local bowling alley, and you might think you've been transported back to the 1950s. The air smells of hot dogs. There's a jukebox in the corner. And there are those same silly shoes your parents and grandparents wore when *they* bowled.

Don't be fooled, though. Bowling is as high-tech a sport as any other. And the technological changes have been significant. They're easy to miss, though, because they're pretty much invisible.

Few non-bowlers know that a thin layer of mineral oil is applied to the first two-thirds of a bowling lane. Oil reduces *friction*, the resistance of objects to sliding. The oil is applied mainly to protect the lanes from damage. But it also has a huge impact on the game because it affects the motion of the ball.

In the 1970s, oil was sprayed on the lanes haphazardly, usually by hand. That made bowling more difficult. The balls moved erratically, skidding and veering unpredictably. Today, $40,000 machines apply oil to lanes in precise patterns. The perfection of machine-oiled lanes helps bowlers control the path of their balls, leading to more strikes, says Paul Ridenour, a research engineer at the United States Bowling Congress (USBC). He tests all the factors that can affect a bowling game and uses his findings to set the official standards for bowling equipment.

The Hook



In this hook shot, the bowling ball spins sideways (blue arrows) as it slides forward down the oiled part of the lane. When it reaches the non-oiled part, it breaks—swerves sideways—and rolls into the pocket, the spot between the top pin and its neighbor.

Bowling balls have come a long way too. The "house balls" you use at the bowling alley are made with the same simple, solid plastic used in the 1970s. But competitive bowlers such as the Tang brothers prefer modern, multilayered balls made from additive-enhanced plastics with holes custom-drilled to suit hand size and bowling technique.

If you could peel back the layers of a modern bowling ball, at the center you'd find a dense inner core. With weird shapes and names to match—names such as Nucleus and Orbiter—the cores are designed to alter the balls' *moment of inertia*. Moment of inertia is a measure of how weight is distributed in an object.

The distribution of weight in a modern bowling ball can give it "trick" properties, causing it to change speed and direction partway down the lane. In particular, the core can help a bowler perfect the single most important shot in bowling: the hook.

Bowlers know that their best chance at knocking over all the pins is to hit the "pocket," the space between the head pin and either of the two pins beside and behind it. Ideally, the ball should not hit the pocket straight on, but from the side, at an angle. How can you get a bowling ball to arrive at the pocket at an angle? Hook it.

A bowler rolls a hook shot by giving it a strong sideways spin on launch. For the first half of the trip down the lane, the ball mainly skids on the oiled lane. But once it leaves the oiled part of the lane, the ball "breaks." It encounters friction and begins to travel sideways, veering toward the pocket.

A ball with a dense inner core can hook even more strongly. As it rolls down the lane, it gradually changes its orientation, putting a fresh section of ball in contact with the oily floor. That produces more friction when the ball reaches the dry part of the lane, allowing for a stronger hook. An ordinary ball collects oil on a single unchanging ring around its surface, which means less friction and less hook.

Pore Reducer

Ridenour and his team made a surprising discovery recently. "We found that the single biggest influence on hook wasn't the core, but the *cover stock*, the material covering the outside of the ball," he says.

The key factor to improving the hook turns out to be *porosity*, the roughness of a surface at the microscopic level. An extra-porous ball effectively has microscopic spikes on it, which help it gain the friction needed to hook even on an oily lane. "You really can't feel the difference," says Ridenour. "But you can see it when the ball hooks."

The USBC recently imposed new limits on bowling ball porosity to maintain the challenge of the game. "Somebody's always going to want to build a better mousetrap," says Ridenour. "Our job is to make sure that those mousetraps don't give bowlers an unfair advantage."