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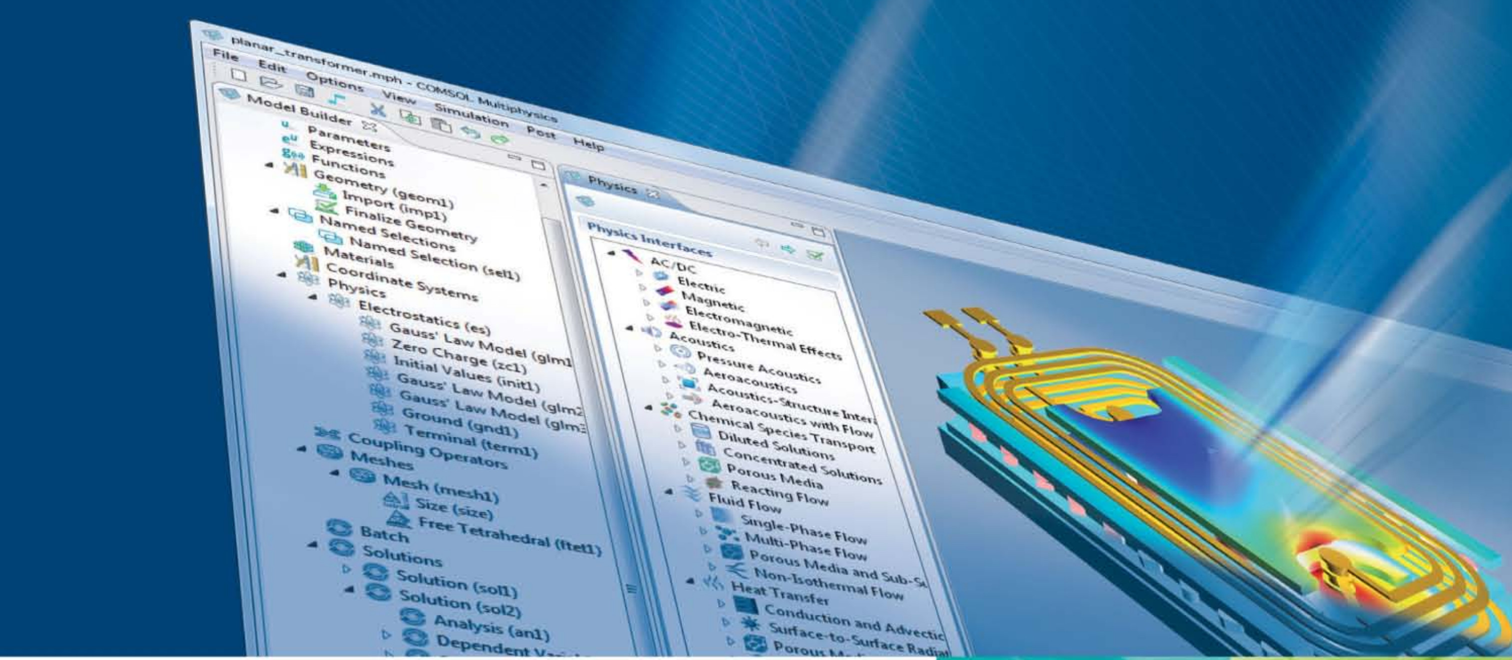

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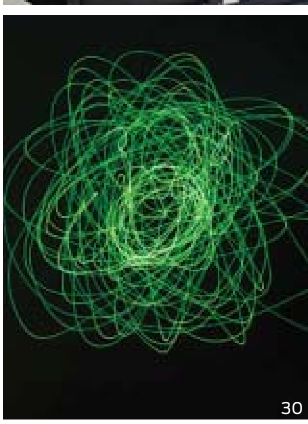

OCEAN DRONE: Rutgers scientists send a subsea probe [top] across the Atlantic; diode lasers can at last produce pure green light [bottom left]; and Haiti's Internet links survive [bottom right].

COVER:
BEACH PHOTOGRAPH: GETTY IMAGES; 3-D TABLET: JOE ZEFF DESIGN

THIS PAGE, CLOCKWISE FROM TOP: GENE SMIRNOV/WONDERFUL MACHINE; ROBERTO SCHMIDT/AFP/GETTY IMAGES; RYANN COOLEY

COVER STORY

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WORLD'S END: *IEEE Spectrum* Executive Editor Glenn Zorpette contemplates his reflection in the ceremonial South Pole marker.

PHOTOS: TOP: GLENN ZORPETTE; BOTTOM: HONDA

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EXPLORING ANTARCTICA

Frigid, beautiful, and mysterious, Antarctica is the last wild continent. Executive Editor Glenn Zorpette spent a week there, hopscotching around McMurdo Station, the main U.S. base, and spending a couple of days at the South Pole. He came upon mummified seals in the famed Dry Valleys, with their delicate, arid ecosystems, and encountered Adélie penguins on the sea ice and at the world's southernmost rookery, at Cape Royds. He visited the century-old huts of the original polar explorers, and successfully completed the "survival school" training required of all official visitors. You can see the highlights of his trip in his two-part audio slideshow. Part one is at http://spectrum.ieee.org/antarctica1.

ONLINE FEATURE

JAPAN MAKES PRESENCE FELT IN NEW PATENT POWER SCORECARD

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Even as the global economic recession took a toll on R&D at U.S. companies, severely affecting patent pipelines, Japanese companies seem to have taken the crisis as an opportunity, according to our annual report compiled by 1790 Analytics. See where your company ranked at http://spectrum.ieee.org/patentscorecard2010.

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LOOKING AT THE GENDER GAP

Despite the abundance of outreach efforts to bring more women into engineering, there's still a large gender gap. Why are women still underrepresented? Does it matter? And what can be done to close the gap? Four IEEE members with experience on these issues weigh in.

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The IEEE University Partnership Program has gone global. Peking University and Tsinghua University, both in Beijing, are the first schools outside the United States to join the UPP.

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back story

GENE SMIRNOV/WONDERFUL MACHINE

They All Live for a Yellow Submarine

A JOURNALIST NEED not be an expert, but it sure can't hurt. And this month we can boast that our feature freelancer's expertise includes a Ph.D.

Boston-based Ari Daniel Shapiro [above, right], who produced both a podcast and an article for us about the first remotely controlled oceanographic probe to cross the Atlantic underwater, has spent years doing such things as putting electronic tags on killer whales off Norway. For his *IEEE Spectrum* story, though, he traveled only as far as Rutgers, the State University of New Jersey, in New Brunswick.

There he found a team of oceanographers studying far-flung spots with a new type of robotic probe, an oceanographic glider. The nerve center of their operation is the Coastal Ocean Observation Lab, or COOL Room, as the scientists have dubbed it.

"I took a late train and arrived in New Jersey around 11 p.m.," recalls Shapiro. "I strolled into the COOL Room about a half hour before midnight, and yet the place was just pulsing with all this science energy."

That's because he'd timed his arrival to coincide with the final moments of a journey that had begun more than seven months earlier, when the glider left New Jersey waters on its pathbreaking trek across the Atlantic. Shapiro had followed the little sub and the scientists running it pretty much the whole time, so he was able to get a lot closer to his subject than is typical. "Usually when I do a story, the turnaround time is a few weeks at the longest—often just days," he says. Giving freelancers plenty of time to do their jobs can be a real plus, for them and for readers, as you will appreciate when you read "Yellow Submarine." ❑

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, the first Update page is in *IEEE Spectrum*, Vol. 47, no. 3 (INT), March 2010, p. 7, or in *IEEE Spectrum*, Vol. 47, no. 3 (NA), March 2010, p. 11.

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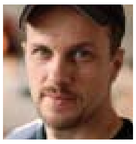
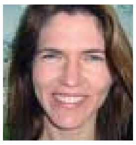
SIDD BIKKANNAVAR and **DAVID REDDING,** who wrote "The End of Blur" [p. 42], work at NASA's Jet Propulsion Laboratory. Bikkannavar first encountered *IEEE Spectrum*'s staff in the Australian outback, where he was helping to run a solar-car race the magazine was covering. Both authors say they stumbled into careers in optics. Redding did so while working on control systems for positioning laser beams and "discovered we didn't really know how to point mirrors." He got curious and, as he puts it, "one day I woke up an optical engineer."



RYANN COOLEY was intrigued by the opportunity to photograph lasers for "Lasers Get the Green Light" [p. 30]. Wearing red goggles, he used low light and 5- to 10-second exposures to paint shapes with a laser on a white surface. Because light needs particles in the air to define a beam, Cooley used a fog machine. Not just a studio photographer, he has shot pictures in over 45 countries.



EMILY COOPER illustrated "Yellow Submarine" [p. 36] using LightWave 3D, an animation program that lets her build models in 3-D and then transfer them to 2-D. With a background in geology, Cooper "gets a kick" out of creating maps like these, because she can use actual topographic data from satellite images. Her first map project was for *National Geographic Adventure*.

JASON HEIKENFELD, an IEEE Senior Member, doesn't own an electronic reader, even though he and his colleagues in the University of Cincinnati's Novel Devices Laboratory are working to develop the ultimate e-paper technology, which he describes in "Lite, Brite Displays" [p. 22]. Meanwhile, he's got his eye on Plastic Logic's new Que, which can display newspaper layouts with photos and headlines in addition to straight text. "I am an avid reader of *The Wall Street Journal*," Heikenfeld says, "but I hate all the paper and the fossil fuels used to ship it."

JONATHAN G. KOOMEY's discovery of a technological advance that's even faster than Moore's Law was probably inevitable [The Data, p. 56]. The former Intel researcher is a master number cruncher who's now a project scientist at Lawrence Berkeley National Laboratory, a consulting professor at Stanford, and a frequent guest on National Public Radio and the BBC. He shares the secrets of his craft in his 2008 book *Turning Numbers Into Knowledge: Mastering the Art of Problem Solving* (Analytics Press).

GENE SMIRNOV shot photographs for "Yellow Submarine" [p. 36] in two stages: on a boat for the glider's launch and in the control room when it reached the finish line. Not getting seasick, he says, "was a battle. If one person goes, everyone goes. You have to keep your eye on the horizon." He had no regrets about that choppy ride when, months later, he waited until 3 a.m. with the scientists and then got to celebrate the completion of the glider's remarkable transatlantic trek.

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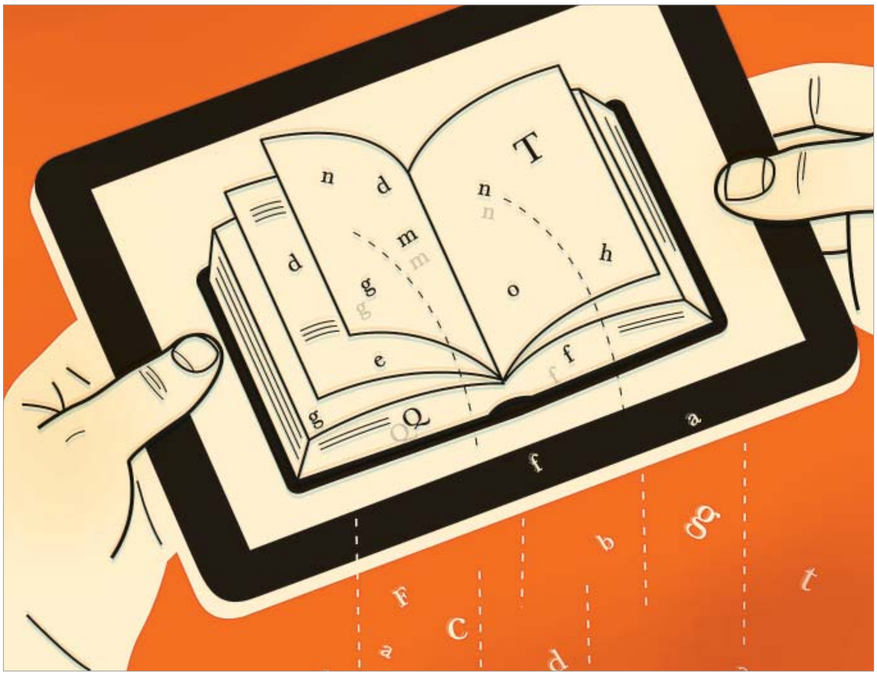
CLOCKWISE FROM TOP RIGHT: GRIGORIEFF PHOTOGRAPHY; ANDY KAHL; JASON HEIKENFELD; NATHAN KURZ; RYANN COOLEY

spectral lines

The Perfect Portable Display—Will It Ever Be Less Than 10 Years Away?



HARRY CAMPBELL

The iPad, Apple's much-anticipated tablet computer due out this month, isn't going to revolutionize the display industry. It doesn't sport a bright organic LED display. It isn't even wearing the latest Pixel Qi technology, which combines LCD technology with a black-and-white reflective version for easy viewing in bright sunlight.

The iPad uses a simple full-color LCD, backlit with LEDs, the kind of display you see today on many flat-screen televisions and computer monitors. Apple's decision to go with the LCD isn't particularly surprising. The iPad will be used to display photos and videos, and to do that it needs a full-color, full-motion display. So E Ink and its monochrome brethren are out. OLED technology is just too expensive right now, and Pixel Qi is a compromise—it gives up a bit in color saturation to pick up that visibility in sunlight.

A version of this article appeared in IEEE Spectrum Online's Tech Talk blog on 27 January.

But the choice of LCD technology also means that, in spite of the vast library of e-books that will be available for the iPad, this device is no e-book reader. While I'm not an e-book convert myself, the folks I know who carry Kindles everywhere read them outdoors as much as in, often in sunlight, and that just won't be possible with the iPad's LCD screen.

The iPad will, however, affect the world of displays, says Jason Heikenfeld, an associate professor in the Novel Devices Laboratory at the University of Cincinnati and author of our feature "Lite, Brite Displays," in this issue. Because the iPad will allow consumers to purchase magazines and other publications with the ease of buying an iTunes track, it will increase the movement to digital media. This will up the demand for a do-it-all screen that can display full-color motion video as well as easy-to-read text, and it may speed up the advance of the state of the art.

But where, exactly, is the display of the future right now? You know, the cheap, portable, low-power, easy-to-read-under-any-and-all-conditions screen we've been saying is 10 years away for, oh, the last 20 years or so?

In his article, Heikenfeld describes a half-dozen different technologies that are now coming out of different labs to vie for control of the e-paper display market—estimated to be about US $10 billion by 2018. And yes, these technologies are about 10 years away from commercialization.

So I guess I won't be tossing out the pile of books on my nightstand to download my bedtime reading from iTunes just yet. Don't get me wrong—the iPad is a sweet computer. And strangely enough, in all its succinct simplicity, it may be just the thing for very late Internet adapters like my 70-plus-year-old aunt, who's never used a computer, only has a landline, and has no patience for service people, boxes with blinking lights, tangled wires, and enigmatic technology. But it's certainly not a printed-book killer, or even a Kindle killer for that matter.

I love the idea of unlimited access, and LCDs like the iPad's are great for digging for information and viewing multimedia content. But for reading for relaxation (which, for me, often means outdoors in a comfortable horizontal position) they just won't do. Maybe someday, the new displays now in the works—the ones that are once again just 10 years away—will.

—Tekla S. Perry

forum

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WHEN LOSERS ARE WINNERS

I HAVE BEEN impressed with *IEEE Spectrum* ever since I became an IEEE member. It is easily among the best technical publications on the market. But your judgment of the Chevrolet Volt as a loser ["Discharged," Winners & Losers, January] is one of the most misguided pieces I have ever read on energy conservation. The article fails to address an important point: The total energy investment and environmental impact of producing and distributing the gasoline needed to drive a traditional car is quite different from the total impact of the electricity needed to drive an electric car. If we are to truly compare electric and electric hybrid vehicles to their traditional counterparts from an environmental perspective, this issue cannot be ignored.

The article also makes the same ludicrous claim that has plagued nearly all evaluations of fuel-saving, cleaner-running vehicles—that green technology makes sense only if it can pay for itself in energy savings. The problem with this reasoning is that the best solution to a problem is rarely the cheapest one. It simply costs more to do a job right. For many of us who proudly drive hybrid vehicles (or put solar panels on our roofs), it is worth the extra expense to drive a cleaner vehicle and have a smaller energy/pollution footprint. Those who are willing to go the extra mile to live a cleaner life are heroes, not freaks. Perpetrating outdated ideas about environmental concerns being only for the tree huggers seems conspicuously incongruous with IEEE's mission.

ANDREW TUBESING
IEEE Member
Socorro, N.M.

DRIVEN TO TECHNOLOGY

ROBERT W. Lucky's engineer's enthusiasm for throwing a technological fix at a social problem ["Driven to Distraction," Reflections, January] may be forgiven, but his call for even more monitoring and control of ordinary citizens cannot. The idea of blocking or restricting service to cellphones in moving vehicles falls short for several reasons, the most obvious being that quite often the caller is a passenger, not the driver. Rather than embracing increasingly invasive technology, we need to encourage personal responsibility, with appropriate punishment for the irresponsible. We can't restrict every possible distraction a driver might encounter, and we should not use the bad behavior of a few to further restrict the lives of the many.

LAWRENCE RACHMAN
IEEE Member
Centerport, N.Y.

WASTE NOT

"FINLAND'S NUCLEAR Waste Solution" [December], about the storage of spent nuclear fuel, has turned me against nuclear power. The nuclear waste produced during the past 50 years amounts to 270 000 metric tons. How much more waste will accumulate during the next 100 years? Even if we decide to stop running or building new plants, what can future generations do with nuclear waste that has a lifetime of 10 000 to a million years?

MAHMUD WASFI
IEEE Senior Member
Burnaby, B.C., Canada

ENTERPRISES SUCH as *Spectrum* gush about how all it takes is smart people and a few bucks wrapped in a reasonable time frame to solve every problem—but when it comes to spent nuclear fuel, the repository required must be good for 100 000 years with no maintenance! Why is it not perfectly fine to make a repository that's good for only 1000 years and then work under the assumption that in 100 to 200 years, with smart people and a few bucks, the technology to solve the problem will be at hand? This approach provides you with a comfortable 500 percent safety margin from a time point of view. And if we don't solve the problem by year 500, we will still have afforded ourselves a good 500 years more to build, rebuild, or upgrade another repository good for another 1000 or more years. Nuclear energy is the only technology that can provide the United States with its near-term future energy needs and do so in an environmentally courteous manner.

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update

more online at spectrum.ieee.org

Satellite Internet Access Withstands Haiti Quake

Wireless broadband links relief agencies

THE 7.0-MAGNITUDE earthquake that struck Haiti on 12 January damaged telecommunications so severely that aid workers and troops found it difficult to coordinate rescue and recovery missions.

First impressions, however, didn't convey the whole story. It's true that landlines were destroyed, cellphone networks were temporarily overwhelmed, and the country's sole link to a fiber-optic undersea cable was severed. But Haiti's multiple links to the Internet—key to networking nongovernmental organizations (NGOs) on the ground—were functional.

Most Haitian ISPs—and indeed ISPs in many poor countries—connect to the Internet via satellite, according to Stephan Beckert, an analyst at TeleGeography Research. So Haitian ISPs were not dependent on the country's lone 1.92-terabit-per-second undersea cable link, which was knocked out during the quake and won't be repaired for some time. The satellite technology, known as very small aperture terminal (VSAT), connects Earth stations to spacecraft in distant, geosynchronous orbits.

"VSAT is usually the cheapest, fastest way to get a country connected to the Internet," says Hernán Galperin, a professor of telecommunications at Universidad de San Andrés, in Buenos Aires. An undersea cable offers economies of scale, but you end up relying on one piece of infrastructure. VSAT, like the Internet itself, tends to be more of a distributed network, with lots of points of connection. For

DOWNED WIRES: Haiti's telecom lifeline to the world runs mainly through satellites, not landlines or undersea cables. In this way, at least, the country has resisted natural disaster better than many rich countries might have.
PHOTO: ROBERTO SCHMIDT/AFP/GETTY IMAGES

update

Haiti, this distributed network infrastructure came as a blessing.

NetHope, a "collaboration of 28 of the world's leading international humanitarian organizations," was one of the NGOs taking advantage of satellite service. The organization was working with San Francisco–based Inveneo to bridge the proverbial last mile by establishing Internet connectivity in the Haitian capital of Port-au-Prince and surrounding areas via VSAT links combined with long-range Wi-Fi. The Inveneo network supports Internet access in and out of the country, carries voice communications, and allows for the collaboration and sharing of resources among up to 20 NGOs.

> "Cheap mobile Internet access could turn out to be one of the small factors that improve education and create economic opportunities for Haitians in the long run."
> –James Cowie, chief technology officer, Renesys

Inveneo cofounder Mark Summer and engineer Andris Bjornson arrived in Haiti one week after the quake hit with the logistical assistance of the housing aid group CHF International. Summer and Bjornson brought with them more than 330 kilograms of equipment, including climbing gear, power drills, power strips, electrical cords, coaxial cable, wireless routers, more than a dozen 5-gigahertz RocketDish parabolic antennas, and 10 Linux miniservers.

Three days after their arrival in Port-au-Prince, Summer and Bjornson reported back to Inveneo via the Internet connection they had helped establish. They had connected a server to a VSAT satellite Internet downlink from ITC Global and installed a local access point for the CHF International headquarters. Then they created two long Wi-Fi links from the headquarters to two different offices of Save the Children Federation in Port-au-Prince. Later that afternoon they established a third link to the offices of Catholic Relief Services.

As Inveneo's partners and other NGOs shift from rescue to recovery to rebuilding, Internet access will continue to play an important role.

"In the long term, getting people access to cheap, diverse, reliable telecommunications will be one important element in Haiti's rebuilding as a nation," says James Cowie, chief technology officer at Renesys, an Internet-monitoring firm.

Because Haiti's mobile-phone penetration rate was pretty high before the quake, Cowie thinks that most of the population will be accessing the Internet through mobile devices in the future. "I'd like to think that cheap mobile Internet access could turn out to be one of the small factors that improve education and create economic opportunities for Haitians in the long run," he says. "But in the face of so much suffering, they obviously have much more serious and immediate concerns to deal with this year."

—Harry Goldstein

Portions of this article appeared on IEEE Spectrum Online on 27 January.

Europe Plans a North Sea Grid

Undersea cables will transport wind, hydro, and solar power

The European Union hopes to generate a fifth of its electricity from renewable energies by 2020. But that can't be done unless its member states can easily move that electricity from one country to another. To that end, late last year nine European countries agreed to build a power grid of high-voltage cables under the North Sea. It would be the first multinational grid designed to address the fluctuating nature of green power generation.

The grid will transport energy generated by a mix of wind, solar, and tidal power between Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway (the only non-EU participant), and the United Kingdom to better balance supply and demand. Energy produced at night in UK wind farms, for instance, could be stored in Norway's hydropower facilities and released the following day. Around 100 gigawatts

CAPRICE OF THE WIND: Robust marine transmission lines could allow Europe to exploit the sporadic production of most alternative sources of energy.
PHOTO: SIEMENS

of offshore wind power are currently planned by European power companies. The UK, in particular, has launched a £100 billion (US $160 billion) program to expand its offshore wind farms, already the world's biggest at around 1 GW, to as much as 40 GW by 2020.

The cable project, estimated to cost the nine countries more than €30 billion ($40 billion) over 10 years, will be financed through a mix of taxpayers' money and private investment, largely from energy companies. Government officials were to begin coordinating the project in February.

The sooner such projects get off the ground, the better, says Sven Teske, an electrical engineer by training and a renewable energy expert with Greenpeace International. "The wind industry is a huge driver behind the push for supergrids and cross-border infrastructure," he says. "The new players need the grids or they won't survive."

Before Europe's grid can handle the planned renewable energy, 34 existing high-voltage alternating current (HVAC) interconnections between neighboring countries will need to be upgraded, at a cost of approximately €3 billion, according to Greenpeace. Another 17 high-voltage direct current (HVDC) interconnections will need to be either built or upgraded at a cost of about €16 billion. And up to 11 new long-distance HVDC supergrid connections will be necessary, at a cost of approximately €100 billion—much more than EU ministers agreed to in December.

Onshore, the EU ministers envision a combination of interconnected smart grids for distribution and connecting decentralized renewable generation, and supergrids that distribute electricity across its member states and beyond. The smart grids would use advanced communication systems as well as new monitoring and control technologies to balance supply, demand, and storage over a region more effectively than is done today.

The supergrids, by comparison, would transport large energy loads to balance electricity surpluses or deficits between regions and also transport bulk electricity from large wind and solar farms. Under plans being shaped by EU policymakers and industry leaders, the supergrids will likely be based on HVDC technology. But HVAC, the mainstay in Europe, will continue to play a role in the region.

The big advantage of HVDC over HVAC is lower electricity loss over long distances. Two types of systems are competing. One, called line commutated converter technology, offers comparatively low energy losses—between 2 to 3 percent for a 500-megawatt transmission over 100 kilometers, including losses in converters and transmission, according to the Greenpeace energy grid study "Renewables 24/7: Infrastructure Needed to Save the Climate." But this system typically requires a strong HVAC network on both sides of the HVDC connection. The other, called voltage source converter (VSC), is a comparatively new technology. VSC-based HVDC offers more control of the power flow, but its total efficiency is still slightly less than that of the commutated design and also requires more cable and more converter stations.

Someday, these planned new supergrids could connect with the European industry-led Desertec project, which plans to transport solar energy from northern Africa under the Mediterranean to Europe. But trying to "bundle too many activities in the early phase" of building new infrastructure could be a mistake, warns Antonella Battaglini, senior scientist at the Potsdam Institute for Climate Impact Research, in Germany. Connecting northern Europe to smart grids and supergrids is, in her opinion, enough of a challenge. —John Blau update

Medical Imagers Lower the Dose

Radiation-lowering techniques were in the works even before studies showed a danger

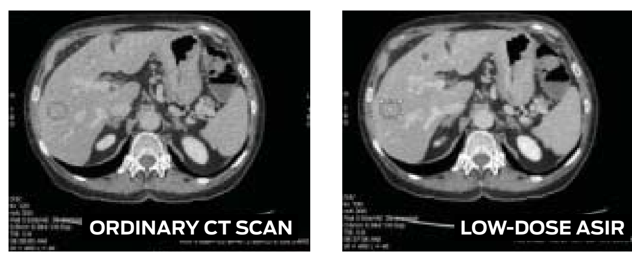
RECENT RESEARCH documenting that CT scans increase the risk of cancer has biomedical engineers looking for new ways to reduce patients' exposure to ionizing radiation.

CT scans, which use multiple X-ray images to build up cross-sectional and 3-D pictures of structures inside the human body, have soared in popularity in recent decades. A study published in December's *Archives of Internal Medicine* found that the number of CT scans grew from 3 million in 1980 to roughly 70 million in 2007. Those 70 million scans could eventually lead to 29 000 cancers, according to the same study. For each year's use of today's scanning technology, the resulting cancers could cause about 14 500 deaths.

But the makers of CT scanners are already taking steps to reduce the radiation dose from a scan, and consequently the risks of cancer. For instance, last year GE Healthcare introduced scanners that incorporate a technique it calls Adaptive Statistical Iterative Reconstruction. An ASIR scan uses a less intense X-ray beam, which means that the resulting raw image can contain more noise. ASIR compares voxels—volumetric pixels—side by side, and if one looks too different from its neighboring voxels, it's assumed to be noise and is removed from the data. ASIR then constructs a high-quality image from the cleaned-up data.

Amy Hara, an associate professor of radiology at the Mayo Clinic in Arizona, studied liver scans made using ASIR. She found that the images were better than low-dose images made without ASIR and required 32 to 65 percent less radiation, depending on such factors as the patient's size. Taking out the noise didn't eliminate any diagnostically important details, Hara says: "We're not losing any actual data. What we're seeing is that it's removing what it's supposed to remove."

Another radiologist, James Earls of Fairfax Radiological Consultants, in Virginia, looked at heart scans done with ASIR and found high-quality images with up to a 90 percent reduction in radiation. Hara says that ASIR studies will have to be done for all the important parts of the body typically scanned—such as lungs and heads—to make sure nothing of diagnostic importance is lost.



CATCH FEWER RAYS: Tricks of image reconstruction spare the patient by making every X-ray photon count.

PHOTO: IAN HOOTEN/GETTY IMAGES; IMAGES: GE HEALTHCARE (2)

Siemens has a similar approach that it calls Iterative Reconstruction in Image Space, which it plans to start selling in the second quarter of 2010. The general technique behind both the Siemens and GE technologies has been known for a while, but it's so computationally intensive that it wasn't practical until computers became more powerful and programmers came up with more streamlined algorithms.

Lower-dose CT scanning is a goal of researchers outside the major imaging firms, too. Ge Wang, director of the biomedical imaging division of the joint Virginia Tech–Wake Forest University School of Biomedical Engineering and Sciences, is developing a new low-dose CT technique called interior tomography. While typical scans cover a whole area—scanning the chest to image the heart, say, or the whole head to map out a cochlear implant—interior tomography focuses on a much smaller region of interest. "Data means radiation dose, so if you reduce data, you reduce radiation dose," Wang says. Scanning only the heart, for instance, immediately cuts the X-rays by about half.

When today's CT scanners image the chest, for example, part of the data they collect includes where the body ends and the open air begins. That defined edge provides the image-building

100 GHz The new record for the cutoff frequency of a graphene transistor. IBM researchers beat their own previous record of 26 gigahertz.

algorithm with the reference values that allow it to calibrate the rest of the image and figure out such information as how dense a bit of tissue is. With the more targeted scan used in interior tomography, that reference is missing. Instead, the technique looks for reference points within the image. An air pocket or a region of blood, even a medical implant, scatters or absorbs X-rays in known ways. Finding those points gives the algorithm a place to start building up the image.

Without the hard edges of empty space in the picture, the scanner cannot use the Fourier transform to reconstruct an image, the way standard image-processing systems do. Instead, Wang turns to a trick called the truncated Hilbert transform. Ironically, although the Hilbert transform has less data to work with, the computation is more demanding. It can take 10 minutes to an hour to create an image, depending on the size, but Wang believes that in two or three years he'll find a way to do it much faster.

Researchers hope these and other efforts will cut the cancer risk from CT scans while retaining their value in finding and treating disease. The Mayo Clinic's Hara says there's a growing awareness of the radiation risk. "For a long time it was about image quality, with less of an emphasis on dose," she says. "We all know that CT's very valuable and helpful, and that's been proven. You just want to make sure there's the least risk to the patient."

—Neil Savage

Scientists Solve Mystery of Superinsulators

The opposite of superconductivity might lead to strange new circuits

In 2008 a team of physicists from Argonne National Laboratory, in Illinois, and other institutions stumbled upon an odd phenomenon. They called it superinsulation, because in many ways it was the opposite of superconductivity. Now they've worked out the theory behind it, potentially opening the doors to better batteries, supersensitive sensors, and strange new circuits.

Superconductors lose all resistance once they fall below a certain temperature. In superinsulators, on the other hand, the resistance to the flow of electricity becomes infinite at very low temperatures, preventing any flow of electric current.

Valerii Vinokur of Argonne and Tatyana Baturina from the Institute of Semiconductor Physics, in Novosibirsk, Russia, discovered superinsulators when the pair chilled a thin film of titanium nitride to nearly absolute zero and tried to send a current through it. They found that the resistance shot up to 100 000 times its original level. The effect vanished at higher temperatures. The researchers also noticed that the effect was sensitive to the strength of a magnetic field; as they increased the strength of an external magnetic field, the resistance disappeared.

Vinokur and his colleagues say the effect could make new kinds of batteries possible. In most batteries, there is a certain amount of leakage when the battery is left exposed to air, because air is not a perfect insulator. Thus, an unused battery eventually drains. "If you pass a current through a superconductor, then it will carry the current forever; conversely, if you have a superinsulator, then it will hold a charge forever," says Vinokur. In fact, he points out, a device made from superconductors and superinsulators might lose no heat at all during operation.

WELL CHILLED: Superinsulators like titanium nitride show their stuff only when cooled to nearly absolute zero.

PHOTO: ARGONNE NATIONAL LABORATORY

Vinokur, Baturina, and Nikolai Chtchelkatchev, a theoretical physicist from the Moscow Institute of Physics and Technology, who also has an affiliation with Argonne, recently worked out a theory of how superinsulation works at microscopic scales, which they reported this past December in *Physical Review Letters*. They say that superinsulation, like superconductivity, is caused at low temperatures by electrons that form what are known as Cooper pairs. In a superconductor the pairs move together collectively, which means there is no resistance to impede the flow of current. In a superinsulator, on the other hand, the Cooper pairs repel one another, and thus prevent any current from flowing.

Vinokur says that while the qualitative picture of the phenomenon emerged in 2008, it was only recently that the team succeeded in working out the first set of detailed calculations.

Eugene Chudnovsky, an expert on superconductivity and a physics professor at Lehman College of the City University of New York, says that the nature of superinsulators has been hotly debated by physicists and that the theory by Vinokur and the Russian physicists is promising. Gergely Zimanyi, a physics professor at the University of California, Davis, says the theoretical physics community has "extremely high respect" for Vinokur's work.

So far the theory and experiments have been confined to thin films of titanium nitride, says Vinokur, who intends to investigate other compounds at higher temperatures next. "There are still plenty of unresolved questions," he says. "We can only remind [ourselves] that the microscopic theory of superconductivity appeared almost 50 years after the discovery. In this respect, we are proceeding incredibly fast."

—Saswato R. Das

US $900 MILLION Amount Samsung will pay technology licensing company Rambus to settle their long-running dispute over DRAM technology.

update

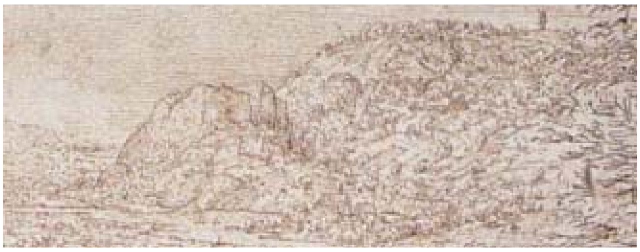
A New Attack on Art Fraud

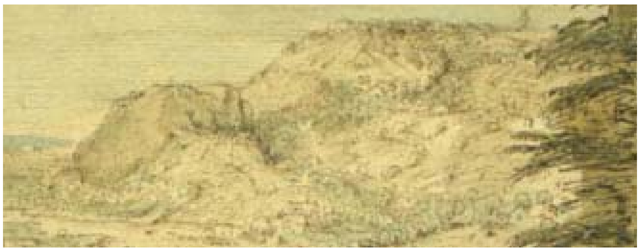
Sparse-coding algorithm spots fakes

Every few years, we're wowed by news of some jaw-dropping sum paid for a previously unknown painting or drawing by a famous artist. But how can a buyer truly be sure that a piece is a legitimate creation of, say, Leonardo or Gauguin? Mathematicians at Dartmouth College, in Hanover, N.H., may have the answer. They recently presented a computer-based statistical analysis technique which they say will help art historians and conservators discover even the most skilled forgery.

Their method, called sparse coding, learns what characterizes the artist's style at a level of detail that is practically imperceptible to the eye of even the most experienced appraiser. It works by examining small patches of a picture and breaking them down to a set of essential elements.

"The aim is to establish for each artist a vocabulary of brush strokes or pencil marks that defines his or her style," says James M. Hughes, a doctoral candidate at Dartmouth who coauthored the research reported in *Proceedings of the National Academy of Sciences*. The style of a great painter like van Gogh is so distinctive that if his craft had been writing memos, it would seem as though he'd had a typewriter with its own custom-made font and type size. No matter the document, it would comprise a set of characters with the same font and proportions. And although cutting up a memo and rearranging the letters would change the message, it would still be clear that it came from the same author. Conversely, a document created by someone else might deliver the exact same message yet not pass a careful examination for authenticity, because the underlying characters would be slightly—or even vastly—different.





SPOT THE FAKE: These drawings were long attributed to Pieter Bruegel the Elder, but only the top one is authentic.
PHOTOS: METROPOLITAN MUSEUM OF ART

The researchers focused on the notion of sparseness, which refers to the ability to represent an image with as little information as possible. The concept is analogous to digital compression.

To test sparse coding, the researchers used it to compare the drawings of 16th-century Flemish artist Pieter Bruegel the Elder with known Bruegel knockoffs. The model was trained on swatches from eight real Bruegel drawings. The sparse-coding algorithm stripped each of them down to a set of basic elements needed to re-create the full drawing. When sections taken from any of the five imitations were stripped down, the model revealed that more often than not, there were readily apparent differences in the sparsity of information, meaning that the imitations were significantly different from the authentic Bruegel drawings.

Asked if sparse coding could be used by a technically savvy art forger to, in effect, reverse engineer an artist's technique, Hughes replies, "The short answer is no." First of all, he says, size matters. The code makes a determination of what the important features are at three different scales—something that would be nearly impossible for a forger to keep track of as he moves a brush across a canvas. Second, he says, sparse coding reports its findings as a set of statistical distributions, making it very difficult to turn that information into something that a forger would find useful.

Hughes says that sparse coding should be viewed as a new addition to the suite of tools used by a conservator or art historian for authentication [see "Art Fraud Forensics," *IEEE Spectrum*, July 2009, http://spectrum.ieee.org/podcast/computing/software/art-fraud-forensics]. James Coddington, chief conservator at the Museum of Modern Art, in New York City, agrees. "Computers can be helpful," Coddington admits, "but art is far too complex to expect that you could just put a painting in one side of a machine and a green light or a red light will tell you whether the piece is authentic."

Coddington says he sees how sparse coding could help identify a drawing, because "there's going to be an internal consistency among the artist's works." But the software won't replace human connoisseurship, historical knowledge, chemistry, and other tools. —Willie D. Jones

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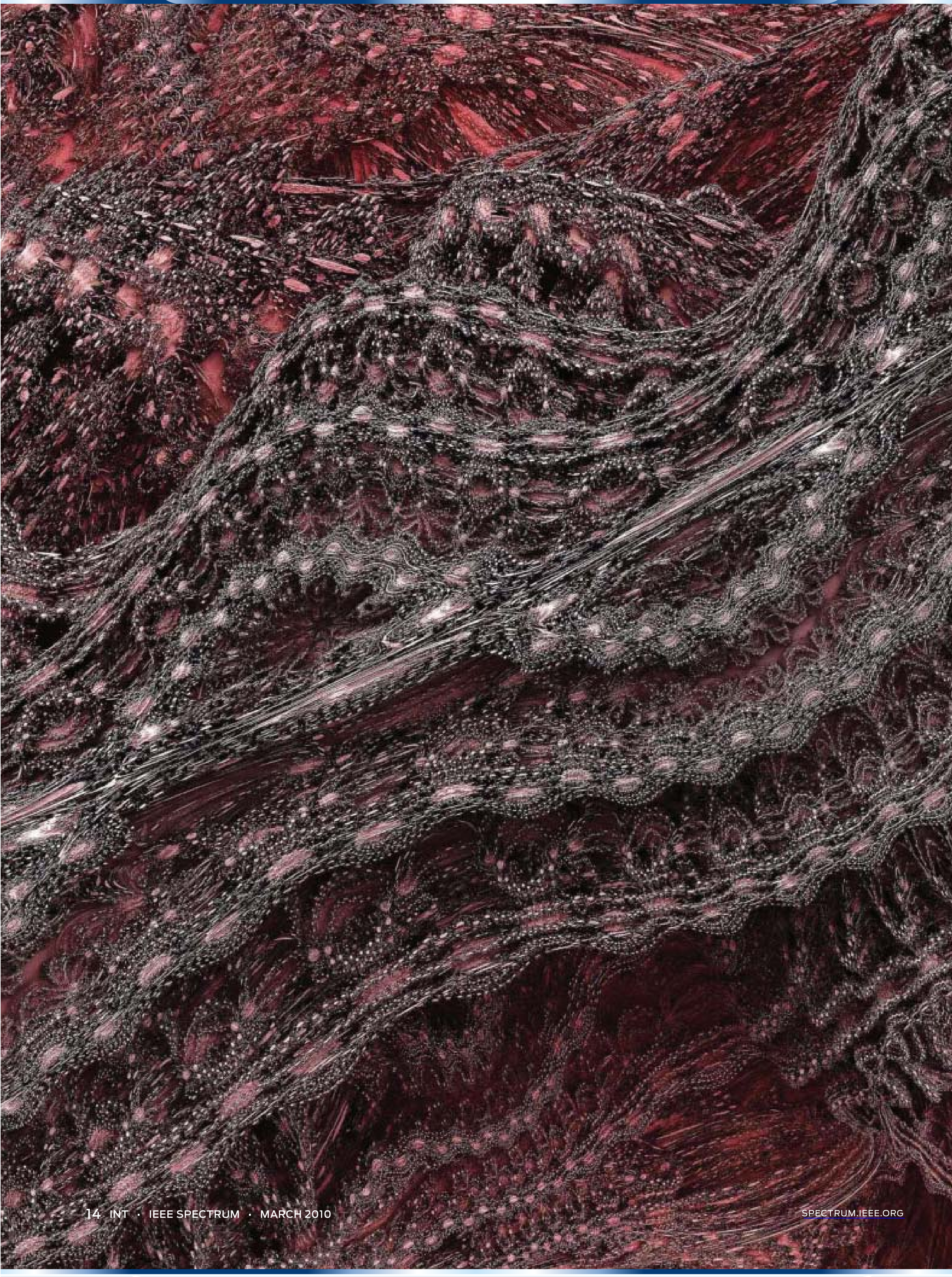

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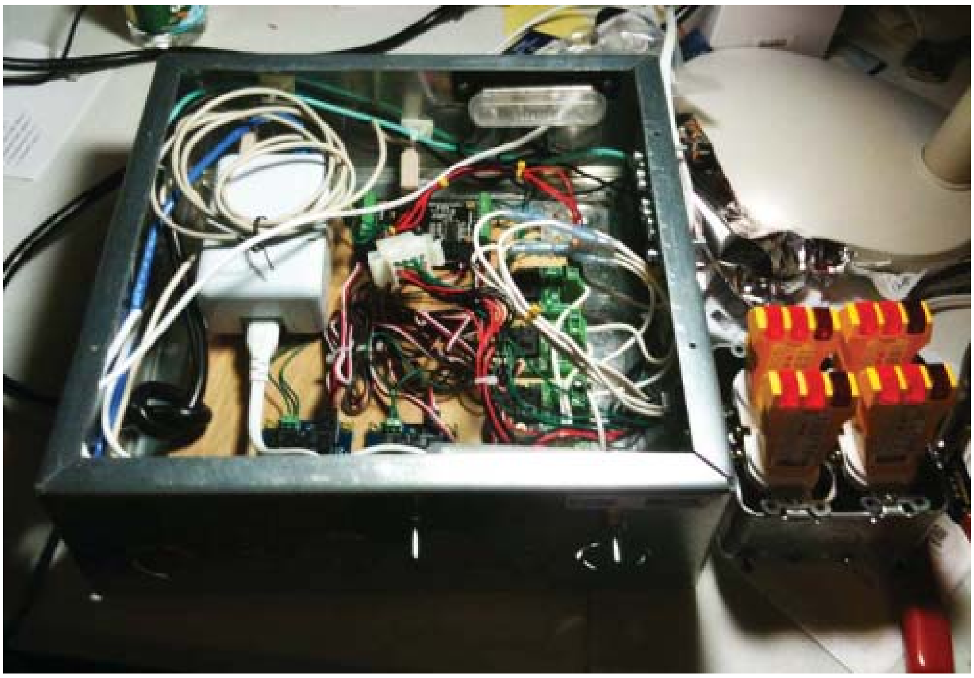
the big picture

PAINTING BY NUMBERS

Who said algebra isn't fun? This ornately detailed figure, which brings to mind the craggy but beautiful contours of a coral reef, is actually a 3-D computer rendering of a mathematical equation. It's an example of a fractal, which breaks the rules of traditional geometry because its area and perimeter are incalculable. The numbers behind these beasties can't be crunched, because no matter how closely you zoom in, the features always look like ever-smaller copies of the entire figure. Widely available fractal-generating software allows anyone to plot simple designs. This highly intricate figure, produced by Daniel White, a Web developer and amateur mathematician based in Bedford, England, is one of many at his Web site, http://www.skytopia.com.

IMAGE: DANIEL WHITE

hands on



REMOTE CONTROL: To manage your appliances across the Web, you need a controller [left] that's nearly as smart—and as big—as a PC. *PHOTO: JAMES TURNER*

THE SMART POWER STRIP

A Web-enabled outlet tells you how much power an appliance is consuming and lets you turn it on and off remotely

I'VE ALWAYS been a big fan of home automation. My first project, back in the days of X10 controllers, let me turn off the lights in the living room from the bedroom. As handy as that was, it required a centralized computer that cost more in electricity than it could ever possibly save. That's true for all too many home automation projects.

A Web-enabled four-outlet power strip would go a long way to solve that problem—you could turn appliances on and off remotely or on a schedule. And while we're at it, shouldn't it show how much power those appliances are using?

This month's project is a smart power strip that does all that. One big caveat: The total build exceeds US $500, which is an insane sum for an outlet strip, no matter how smart it is.

Here's another caveat: safety. Obviously, making a power strip is going to mean working with alternating current. You'll need wire of the appropriate gauge. Make sure none is exposed, and be careful not to confuse signal lines—probably 20 gauge—with AC lines, which should be 14 gauge for a 10-ampere project. And of course, check your local electrical code. I got a very powerful reminder when an upstairs lighting fixture in my house caught fire because of improper grounding. Remember, AC power can kill within the blink of an eye.

The two main components of the build were a SheevaPlug Development module and a Phidgets input/output board with four current-sensing modules and two 10-A dual-relay modules. The Phidgets I/O board is a sweet little guy. Mine has eight digital inputs and outputs and eight analog inputs, which use a standard connector type that also supplies +5 volts and ground. The dual relays need a digital input for each relay (on or off), but they also need a certain amount of "wetting" current—the current needed to break through any thin film of oxide that may have formed on the contact surfaces of the relay switches. That current is supplied by the analog input ports, so I ended up using six analog inputs (four current sensors and power for the two relay modules), four digital inputs (switches), and four digital outputs (LEDs and relays). One of the nice features of the board is that the digital inputs have built-in pull-up resistors, so you can just hook a switch up between ground and the input.

I first attached the relays and the LEDs to the Phidgets board to see if everything worked. The SheevaPlug was going to take a while to arrive, so I used my Mac as a stand-in. Once I had determined that the Phidgets board was alive, I took a standard square electrical box and drilled a number of holes around the base for four switches and four LEDs—I wanted to be able to see whether each receptacle was live by checking an LED next to it. In other words, the LED would be on if—and only if—the relay was active, even if the computer went nuts and started sending garbage to the board. I consider this a basic safety feature, and it's easy to do by running parallel wires to the relay input and the positive side of the LED.

For me, every do-it-yourself project has a milestone, and this one will be remembered as The Build That Made Me

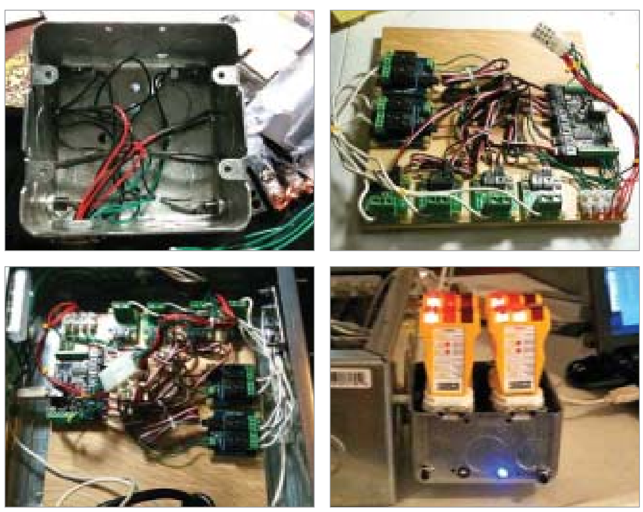
Finally Buy a Drill Press. Using a hand drill, putting the first hole through the electrical box took three drill bits and 20 minutes of the most awful noise. A nice 12-inch (30-centimeter) drill press was on sale at my local Home Depot. With it, the remaining seven holes took about 20 seconds apiece.

Wiring up an AC receptacle makes necking in a VW Beetle seem easy. I took extra care to think out the wiring scheme, which I envisioned in two layers. Up at the top were the four individual neutral (white) wires for the plugs that led to the relays, two live (black) wires that ran to the plugs in common, and two grounds (green). As with most receptacles, you can choose whether to wire the two plugs in common by breaking a metal tab on each side. By breaking one tab and leaving one in place, I was able to supply the live wire in common to each of the receptacles while delivering individual neutral lines for each plug, allowing them to be switched individually.

The second, lower layer has eight wires for the LEDs and five for the switches, along with plenty of cable ties. (I daisy-chained the ground wire on the switches to reduce the wire mess, something I should have done for the LEDs as well.) The two live lines ran to a common terminal strip that would also provide power to the SheevaPlug; the neutrals ran to the current sensors, then to the relays, and finally to another terminal strip. The grounds went straight to a grounding bar attached to the chassis. The LED grounds and switch grounds went to the input and output digital ground terminals, respectively. Finally, the LEDs went into the digital output ports in parallel with the relay control lines for the same circuit, and the switch lines went into the digital inputs. I kept things simple, with digital output 1 controlling the relay that energized the circuit measured by the sensor connected to analog input 1, controllable by the switch going into digital input 1.

A few weeks later, I was back at the drill press with a larger, specially ordered electrical box. One of the things you quickly realize about projects that move a lot of AC current around at significant amperage is that the wires are thick. Too thick, in fact, for the first box to still have room for the SheevaPlug. I had to pull all the components out and move them into a new home. I also special-ordered some bus bars, normally used for marine applications, to safely distribute the hot and neutral lines.

At last, the SheevaPlug came. It turned out to be a real joy, with the Debian Linux operating system, 512 megabytes of onboard storage, an Ethernet port, a normal USB port, a micro-USB port, and an SD slot. At full bore it draws 5 watts.



SMART STRIP: Lay in wires for the buttons and LEDs first [upper left]. Mount an I/O board with sensors and relays [upper right] on a piece of wood—and make sure your enclosure is big enough [lower left]. If you wired correctly, an LED will light up when a plug is live [lower right]. PHOTOS: JAMES TURNER

Rather than create a cross-compilation system for the ARM processor on the Sheeva, I installed the Gnu Compiler Collection and the Emacs file editor onto the device itself, and developed my software right there. I wrote a C-based program that interfaces with the Phidgets APIs to poll the switches on the outlets every 250 milliseconds to see if any have been pressed. If so, the program turns the relay on for that outlet and also for the LED. It further checks a first-in-first-out queue to see if any commands have come in, and every second it writes out the current relay settings and power consumption to a log file. I then wrote a Perl-based Web application that reads the last line in the log file every 2 seconds and displays the current relay settings and power usage, with buttons to send commands to the queue to turn outlets on or off.

Everything worked like a charm. I was able to surf to the power strip's Web server using my iPhone and turn the outlets on and off from anywhere in the house. I could also look at the watts consumed and see whether anything plugged into an outlet was actually turned on. Still on the to-do list: Configure the outlets to be locked out at certain times (so that little Johnny can't turn on his XBox when he should be doing homework, for example), and use the log file to graph power usage over time.

Like many DIY projects, this was enormously fun and educational but not tremendously practical. For one thing, the finished unit is pretty big, about the size of a small PC. It also was pretty durn expensive. I figure it will pay for itself in electrical savings in about 30 years.

—James Turner

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geek life

DIE ANOTHER DAY

Thousands of bodies are already cryonically frozen, waiting for faster computers and medical advances that will undo their cause of death

WHAT IS death? Over the centuries, the line dividing life and death has moved from the cessation first of breathing, then of the heartbeat, and finally of brain activity. But cryogenic methods first contemplated in science fiction may push the line even further. The idea is to freeze legally dead people in liquid nitrogen in the hope of regenerating them at some future date.

Today's cryonics scientists believe that this future may be a mere 100 years away. Alcor Life Extension Foundation, in Scottsdale, Ariz., the world's largest cryonics company, charges US $150 000 to freeze and maintain a body and $80 000 for a head, typically paid for with a life insurance policy.

Ralph Merkle, a nanotechnology expert and a director at Alcor, believes the best approach lies in developing nanorobots that can repair the body at the cellular level before thawing. They would fix or replace diseased and deteriorated tissue as well as the tissue fractures and denatured proteins that result from the freezing process itself. The revival process would, ideally, restore the physiology of dead persons to a pristine level, not only undoing the damage of whatever disease or accident killed them but also enabling them to return smarter and healthier than they ever were in life.

"We're talking about a fundamentally more powerful medical technology than we have today that will continue the evolution of the concepts of life and death," says Merkle, who holds bachelor's and master's degrees in computer science from the University of California, Berkeley, and a Ph.D. in electrical engineering from Stanford. "People will be able to suffer more damage and still fully recover."

CHILL OUT: For a mere US $150 000, you can deliver your corpse to the cryogenicists at the Alcor Life Extension Foundation and wait for medical science to conquer death. *PHOTOS: ALCOR LIFE EXTENSION FOUNDATION*

Before the body is cooled to –196 °C (the temperature at which liquid nitrogen becomes a gas), the person's blood is replaced by a cryoprotective solution that doesn't freeze at those temperatures. Technically, the body and cryoprotective solution are not frozen but vitrified—that is, they solidify into a glassy substance that's free of ice crystals and the damage they can cause. The first step in the future regeneration process would remove this vitrified liquid, letting physicians use the circulatory system as a series of tunnels through which they could run nanomedical robots, nanomaterials, and a removable high-speed fiber-optic network connecting to an external supercomputer.

"It takes about 10^{25} bits to store the molecular structure of the brain," says Merkle. "The processing power to repair the brain alone might be 10^{37} switching operations (10^{31} floating-point operations)—the equivalent of 100 million copies of today's fastest supercomputer running flat out for three years. With Moore's Law doubling computer power every year, we'll have that kind of computational power in a single supercomputer in about 26 years," he adds. "Give it another 10 years and the price will drop from $100 million to $100 000. Somewhere around 2050, that much computational power will be readily available to individuals." And it doesn't matter if Moore's Law slows down, Merkle says: "A person at the temperature of liquid nitrogen can literally wait centuries."

That loose deadline was a selling point for Merkle when he first investigated life-extension technologies for himself and his wife. Cryonics offered the only potential solution that wasn't tied to a person's lifetime.

But is it a solution—or a pointless gamble? In *The Skeptics Dictionary: A Collection of Strange Beliefs, Amusing Deceptions, and Dangerous Delusions* (Wiley, 2003), retired philosophy professor Robert Todd Carroll wrote: "A business based on little more than hope for developments that can be imagined by science is quackery. There is little reason to believe that the promises of cryonics will ever be fulfilled."

Stephen Barrett, a retired psychiatrist in Chapel Hill, N.C., who operates the Web site Quackwatch, a health-care consumer-advocacy network, agrees. "The odds are pretty close to zero that people who are pronounced dead would have any remaining brain function or restorability. Brain cells die fairly quickly and would have to be regenerated in sufficient order and numbers to restore functionality. And then you'd have to restore the rest of the body. The obstacles are so enormous, it's a foolish investment. You're better off putting the money toward improving your life today or doing something worthwhile for others." —Susan Karlin

books

Frank Oppenheimer, the Man Who Made Science Fun

The brother of Robert Oppenheimer marched to the beat of his own drummer

SOMETIMES a biographer can love her subject too much. In the case of a new biography of physicist Frank Oppenheimer, by the respected science writer K.C. Cole, it turns out to be mostly a good thing for all concerned. *Something Incredibly Wonderful Happens* tells the story, from the perspective of a longtime confidante, of the younger brother of the man who led the American effort to create the atomic bomb.

Frank Oppenheimer (1912–1985) was far less famous than his brother, Robert, but he carved out a career in science that was no less fascinating, pioneering the investigation of cosmic rays and championing technology. In 1969, he founded San Francisco's Exploratorium, a science museum that invented a new way to introduce nonscientists to the profession. Stocked with whiz-bang experiments demonstrating the underpinnings of fields such as optics and electricity, the hands-on gallery has been educating visitors ever since.

The younger Oppenheimer did not set out to become an educator. He initially followed in the footsteps of his brother, studying physics at the University of Cambridge and Caltech. While still at Caltech in 1936, Oppenheimer brashly joined the American Communist Party; his participation in its antifascist activities would haunt him years later.

Soon after war broke out in Europe in 1939, Oppenheimer gave up his Communist ties and went to work at the University of California Radiation Laboratory on the problem of refining uranium. He became an aide to his older sibling—by then the director of the secretive Manhattan Project—who had Frank monitor the production of enriched uranium for the atomic bomb used on Hiroshima. After the war, he worked on an early particle-beam accelerator for fundamental research.

In 1947, however, Oppenheimer's earlier involvement with Communism collided with his classified work on the secrets of the atom. He was called before a U.S. congressional committee in 1949 and grilled for the names of other Communists in the nuclear research field. He refused to comply, triggering a firestorm that eventually engulfed his older brother. By the standards of the McCarthy era, there was enough guilt by association with Frank to burn the careers of both men to cinders.

Both retreated into private life. While Robert never did truly recover, Frank eventually found a new calling as a high school instructor and then a university lecturer before establishing his innovative museum.

Cole, who worked at the Exploratorium at one point, delivers a detail-rich account of this remarkable journey that largely absolves Oppenheimer from sin. Of his early Communist flirtation, for example, she concludes he was merely young and foolish, certainly an idealist but never a subversive. Indeed, she turns it into something of a virtue. "Robert's magnetism emanated from his brain, Frank's from his soul," Cole writes. The younger Oppenheimer comes alive on the page in her account of his long quest to reconcile mind and heart.

Indeed, Cole goes on at such length that a bit of editorial restraint would have gone a long way. That said, if you like biography as much as you do science, Cole's book on the other Oppenheimer is a lot like its subject: thoughtful, fun, and full of virtues.

—*Kieron Murphy*

Something Incredibly Wonderful Happens: Frank Oppenheimer and the World He Made Up
By K.C. Cole; Foreword by Murray Gell-Mann; Houghton Mifflin Harcourt, 2009; 396 pp.; US $27.00; ISBN: 978-0-15-100822-3

geek life

Bluegrass and Green Living

Nashville turns a run-down warehouse district into an upscale eco-neighborhood

BEFORE AND AFTER: It took the Gulch 10 years and US $7 million to win the world's strictest environmental certification for neighborhoods. *PHOTO: MARKETSTREET ENTERPRISES*

NASHVILLE SURELY has more musicians than environmentalists. But last year, the Tennessee city became the first in the southern United States to have an internationally recognized green neighborhood.

The city's once-dilapidated downtown industrial zone—24 hectares known as the Gulch—is one of 55 places (as of the end of 2009) in the world awarded the Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND) certification for smart growth, new urbanism, and green building.

Today the Gulch is a cheerful intersection of old and new: revitalized brick warehouses now housing retail shops and trendy restaurants, anchored at one end by steel-and-glass high-rise condos and by a beloved ramshackle blues club at the other. It took a decade and US $7 million for the Gulch's public/private collaboration to turn the site into a self-contained neighborhood of 900 energy-efficient mixed-income residential units and 34 800 square meters (375 000 square feet) of office and retail space, using such green technologies as LED traffic signals and centralized ventilation and water systems.

Nashville is one of 36 LEED-certified neighborhoods in the United States. LEED is the most widely recognized and toughest green-building program in the world. Some 35 000 single-building and neighborhood projects in 50 states and 91 countries participate.

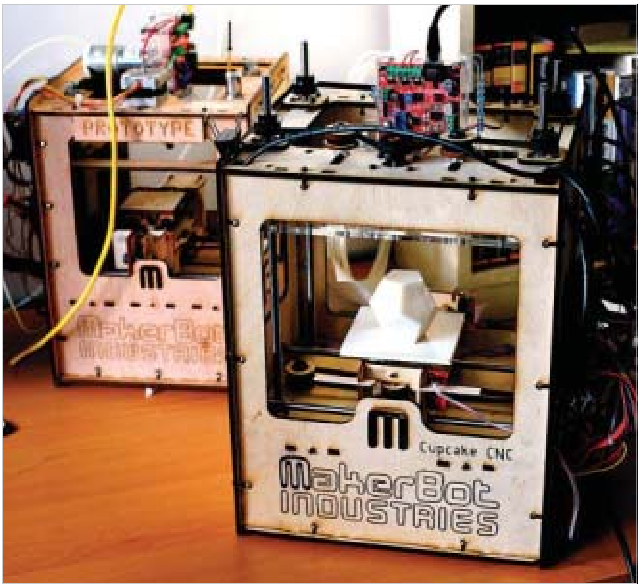
The U.S. Green Building Council developed the LEED program in partnership with the Congress for the New Urbanism and Natural Resources Defense Council in response to rising greenhouse emissions, energy drains, and development infringement on farmlands, wildlife habitats, and water quality. With buildings responsible for two-fifths of U.S. energy consumption and carbon dioxide emissions, greater building efficiency can meet 85 percent of future U.S. demand for energy.

LEED-ND criteria encourage designs that put homes, jobs, and services within reach of one another by foot or public transit and spur more-efficient energy and water use, building reuse, materials recycling, and heat-emission reduction. Until 2007, only individual buildings were rated. The USGBC spent two years in a pilot program using the results of 238 projects from 39 states and six countries—including those from the Gulch—to develop the LEED-ND rating system, to be released early this year.

The process can challenge even seasoned developers. "Getting LEED certification was harder than we ever thought it would be—certainly, we didn't think it would take 18 months," says Dirk Melton, development director for the Gulch's developer, MarketStreet Enterprises. The Gulch was also aiming for the more stringent Silver level of certification. "We had to do a lot more legwork in terms of engaging city authorities and experts to help us with the various credits," he adds. "But because we were part of the pilot program, we probably had to do a lot more homework than will be necessary for future applicants."

Melton says that municipalities as well as private developers can shepherd a neighborhood through the certification process. Indeed, in some ways it's easier because of the often-lengthy commitment needed to recoup initial investments. Energy-efficient technologies, he says, are often more expensive up front, so they require a longer payback time than a typical development company might have. "It's pretty unique in the real estate community to make any kind of investment that isn't recouped in a couple of years," he says. —SUSAN KARLIN reflections BY ROBERT W. LUCKY

Almost Teleportation



MEET THY MAKER: Inside a MakerBot's frame, a computer squirts hot plastic onto a platform it controls via stepper motors. The result: 3-D photocopies. *PHOTO: BRE PETTIS*

TELEPORTATION HAS been an enduring dream of science fiction. We're nowhere near the "Beam me up, Scotty" stage, but there are already hints of teleportation today. It started, in fact, in the 1970s, when—first with facsimile and then with computer networking—we began to reproduce paper documents at a distance by scanning, transmission, and printing. For all practical purposes, the document has been teleported. Now, what about physical objects?

Transmission of the information necessary to reconstruct an object is not a problem; what we need are 3-D scanners and printers. I'm not sure there are any 3-D scanners, but there is a fascinating open-source effort going on now to develop a 3-D printer, called the MakerBot. The MakerBot works like a computer-controlled hot-glue gun, squirting melted plastic onto a platform moved by stepper motors. Under software control, it can reproduce plastic objects up to about the size of a small milk bottle.

You can buy a MakerBot kit for about the cost of a typical personal computer. When assembled, it looks like a trap for small animals made with an Erector set. No one would confuse it with a consumer product, and I get the impression that it takes an engineer to run it. But then, so did the first personal computers (remember the Altair and Heathkits?). Engineers should find the idea intriguing. When I saw a recent demonstration, one attendee cried out, "I'm really excited, and I want to buy one, but I don't know why!" I thought that this perfectly encapsulated the experience.

There is already a dedicated group of experimenters out there assembling MakerBots, using 3-D modeling software to describe objects, and using the MakerBot to create teakettles, Darth Vader heads, custom Lego blocks, ornaments, model railroad buildings, and more. While this sounds like a cute hobbyist toy, what it portends for the future could be very significant.

The last piece of the teleportation puzzle is a 3-D scanner that generates data in a form that the MakerBot can use. Such a scanner doesn't seem impossible. In the meantime, the early adopters are sharing their modeling data; there is a growing library on the Internet of designs for MakerBot objects. These libraries are an inevitable step along the way to widespread use, just as they were in the programming world. (Think of the journey from assembly language to scripting.) Others gradually come up with improvements, which are shared as well. The result is hardware upgrades via e-mail. Eventually, there will come a time when there is little point in crafting your own object models. Someone out there will have already done whatever it is you need.

All this in itself is startling, but looking to the future, there are some fantastic possibilities.

The first possibility is recursion. It is a word that we apply in mathematics and programming, but couldn't it describe a property of hardware? In other words, couldn't a MakerBot make a MakerBot? Obviously, we can't yet render the motors and electronics, but the physical structures of the MakerBot could be made by the MakerBot itself. So you buy one for yourself, and then give duplicates to your friends, who could then make more duplicates for their friends until it becomes a viral MakerBot infection. (Of course, commercial versions of the MakerBot will probably come with industrial-strength copy protection.)

Let's let our imaginations run even wilder. With modular construction, we could use a MakerBot to make a bigger MakerBot, which in turn could make a bigger MakerBot. The electronics could, of course, stay the same while the physical world grows—or shrinks, for that matter.

As MakerBots proliferate, will they evolve? I imagine they will—not just planned mutations but random ones as well. We might see survival of the fittest, whatever "fittest" means in a MakerBot world. The possibilities are endless.

But enough dreaming—reality is exciting enough. Beam me up, Scotty! Or if not me, at least a plastic doll. ❑


The New York Times
SONY
Continue Reading
Books
All Notes
Collections
More
1/5
My Readius
News (New 7, unread 15)
Latest: Engadget Mobile - Polymer Vision shows
Messaging (New 3, Unread 5)
Latest: Carice van Houten - Let's meet!
Documents
- Books, Summaries, E-papers, E-magazines
Audio
- Podcasts, Audio books, Music
Extras
- Maps, Pictures, Games
READIUS

Cover Story

Lite, Brite Displays

Kindle, iPad, Droid—these compact mobile devices are essentially all display. But the screens aren't all we'd like them to be. Yet.

By JASON HEIKENFELD

It's 2020, and it's sunny outside. In fact, it's so bright in your kitchen that you have to squint to see your grapefruit. You flip on your e-reader and the most recent e-issue of *IEEE Spectrum* pops up on-screen, the colors and text sharp and brilliant in the sunlight. There's e-mail to answer, but you want to make the early commuter bus, so you roll up your e-reader and stuff it in your jacket pocket.

On the bus, you switch the device to physically rigid mode and half the screen becomes a large keyboard. You bang out a few messages, then watch a short video. All the while the unit is charging its battery through a built-in organic solar cell.

That's my vision of the future of periodical literature—or rather, the future of periodical delivery. It combines the orderly, portable, full-color format of today's print publications with the flexibility, timeliness, and multimedia capabilities of online magazines. And the only component still lacking is a screen that's easy on the eyes in all sorts of lighting conditions, displays full-motion and full-color images, is rollable and durable, and uses precious little power.

Like the jet pack, it always seems to be a decade away. So why should you believe me now when I tell you that the do-all e-reader will be available in a decade? Read on.

NO FEWER THAN HALF A DOZEN different technologies are emerging from laboratories to compete to be the e-reader screen of the future. The stakes are high: Research firm DisplaySearch estimates that the market will near US $10 billion by 2018, powered by a compound annual growth rate of 41 percent.

To understand the technical challenges, first consider where we are today. Today's electronic readers, such as the Amazon Kindle and the Sony Reader, meet two of my criteria for the ideal e-reader: They're easy to read in bright light and use minimal power. These monochrome displays, sometimes called electronic paper or e-paper, use a kind of electrophoretic technology developed by E Ink Corp., a company in Cambridge, Mass., that was spun out of the MIT Media Lab in 1997. An electrophoretic pixel comprises numerous tiny capsules that contain a mixture of oppositely charged pigment particles, typically carbon for black and titanium dioxide for white. A voltage attracts or repels the pigment particles within the capsules from the screen, depending on whether a white or a black pixel is needed at that spot. Like mixing paints, with the right voltage control the system can also leave the particles in a partially mixed, or grayscale, state. It doesn't need much power, because the pigments simply reflect—or don't reflect—the ambient light, and they don't need any power to maintain their most recent state. An electrophoretic display takes 200 milliseconds to switch images. So if the image on the display changes every 60 seconds, in 1000 hours of continued use the display would effectively draw power for only about 3 hours.

E Ink has spent over a decade getting to this point and is still refining the basic technology. But already these displays are really simple to produce. Manufacturers purchase ready-made film containing the pigment-filled capsules and simply laminate it to an underlying panel that carries the drive circuitry. The first generation of E Ink displays used silicon transistors and glass panels; the second, due this year, will use organic transistors and plastic panels. This second generation includes Polymer Vision's Readius and Plastic Logic's Que; the Readius is literally paper thin, and it can be rolled and unrolled tens of thousands of times.

Now for the downside. Electrophoretic technology has limited potential for displaying full-color images. That's because it hasn't really solved the brightness challenge. Imagine that you're going to paint a wall white that's now a very dark brown. You'll need at least three coats of white paint to cover that brown. Electrophoretic pixels have a similar problem, because the black particles are never fully hidden by the white ones. So the white reflectance is only about 40 percent, compared to 80 percent for a sheet of paper.

If you try to get around this problem by using more particles, you run into problems with switching speed. Electrophoretic pixels already switch slowly because the layer of electrophoretic ink is relatively thick, about 40 micrometers, and the voltage applied to the pixel must be spread across the entire thickness. The level of liquid crystal material in LCDs is only a few micrometers thick, and that's one reason they're so much faster. Electrophoretic technology also can't do video; the switching speed is just too slow.

Want color? The current approach is to add a red-green-blue color filter array over the pixels. The problem is that this reduces the brightness by a factor of

OPENING IMAGE: SEAN MCCABE

Screen Play

At least six technologies are in contention to be the display of the future

ELECTROPHORETIC PIXEL

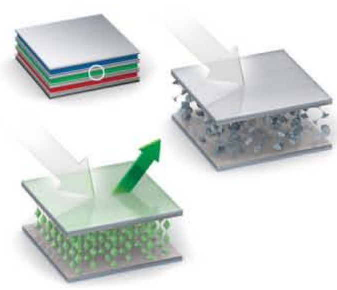
Black and white pigment particles with opposite charges migrate inside capsules, depending on the applied voltage.

PRO Is simple to produce.
CON Slow switching limits video capability; full color is dim.
WHO E Ink
STATUS Available now

3QI MULTIMODE

This LCD variant both reflects and transmits light.

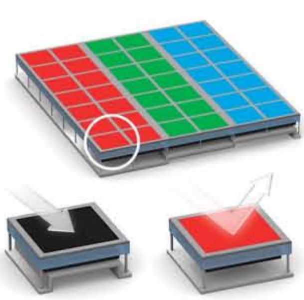
PRO Consumes minimal power and is visible indoors and out.
CON Brightness and color saturation are both compromised.
WHO Pixel Qi
STATUS Expected to ship this year



CHOLESTERIC LCD

Liquid in each of three layers has a molecular structure that matches a different color of light.

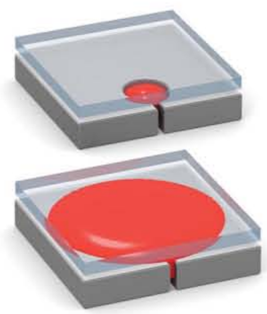
PRO Layers go transparent and can be stacked.
CON Inefficiencies limit overall brightness.
WHO Kent Displays
STATUS Available in Japan



MIRASOL

A MEMS device moves a membrane to and from a stack of optical films, changing the wavelength of the light reflected.

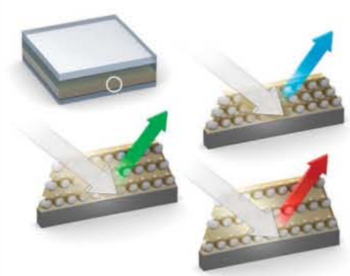
PRO Has crisp, fast video, low power consumption, and visibility in sunlight.
CON Is expensive to produce; white is a challenge.
WHO Qualcomm
STATUS Available in small screen sizes



ELECTROFLUIDIC PIXELS

Voltage pulls an inklike fluid out of a small reservoir and into view.

PRO Materials and mechanism are similar to ink on paper; switches fast enough for video.
CON Coming late to the race.
WHO Gamma-Dynamics/University of Cincinnati
STATUS In laboratory



PHOTONIC INK

Electrically active polymers between nanobeads swell or shrink to change the size of the optical cavity and therefore the color.

PRO A single pixel can generate any color.
CON To date, brightness is a problem, and devices have limited lifetimes.
WHO Opalux
STATUS In laboratory

EMILY COOPER

three, because each primary color filter passes through only one-third of the visible spectrum of light. So, at each color pixel the display can reflect only 10 to 15 percent of the available light. The first color electrophoretic displays, expected to reach consumers late in 2010, will use very weak color filters; this will crank up the brightness at the cost of color saturation.

For bright, full-motion color images on portable screens, LCDs dominate. First developed in the early 1970s and almost continuously improved since then, LCDs are hard to beat for almost any characteristic *except* efficiency. That's why Time Inc. recently presented its futuristic concept version of an electronic *Sports Illustrated* on a standard LCD, and Apple's new iPad sticks with this established technology.

LCDs are energy hogs for several reasons. For one, an LCD works by polarization, which means that at least 50 percent of available light is lost because it doesn't pass through the polarizer. It loses more light to color filters, ultimately wasting about 90 percent of the light from its backlight. So the backlight has to be intense, and it saps power, but that's the only way you can get a bright, crisp, vivid image. The upshot is that LCDs convert electricity to viewable light with pitifully low power efficiency—just 2 to 3 percent.

Worse yet, the readability of both LCDs and the newer organic LED displays, which must also rely on electrically generated light, dramatically deteriorates outdoors. The displays simply cannot compete with direct sunlight, which is about a thousand times as bright as typical indoor lighting. Even a slight sunlight reflection is far brighter than the light coming out of an LCD screen.

The final blow against LCD as the ultimate display technology is that for many people, long-term viewing of an LCD strains the eyes. E-paper displays generally don't cause eyestrain because they automatically reflect—literally—the brightness of your surroundings.

So today's e-paper has readability and low power, and LCDs have brilliant colors and full video motion. Is there a technology that can do it all? A few of the contenders are bistable liquid crystal, cholesteric liquid crystal, microelectromechanical systems (MEMS), electrowetting, and electrofluidic technology, as well as new generations of electrophoretic technology.

To Market, to Market

AMAZON KINDLE
DISPLAY
Electrophoretic pixel from E Ink
RELEASED
2007

G-CORE MINI-CADDY
DISPLAY
Mirasol from Qualcomm
RELEASED
2009

QUE PROREADER
DISPLAY
Electrophoretic pixel from E Ink on proprietary plastic display
RELEASED
2010 (planned)

These technologies exploit radically different principles and offer varied features. None of them yet provide the ultimate 2020 display experience of low power, readability, bright color, and full-motion video. But at least a few of them are getting close to providing color e-paper that would be as bright as the monochrome Kindle.

FIRST OUT OF THE LAB later this year will be the multimode display, from Pixel Qi, in San Bruno, Calif. This display takes a brute-force approach, combining reflective and transmissive liquid crystal technologies in an attempt to get the best of both worlds. The display, called 3Qi, operates in three different settings: standard color LCD, black-and-white e-paper, and a limited color e-paper mode. If you're using your laptop in bright sunlight, you would manually switch to the e-paper mode, relying on reflected light; in a dark environment you would switch to the backlit LCD. Combining all these features into a single product causes some loss of maximum brightness and color, but the versatility and low power consumption may make it compelling for consumers, at least for now. [See "Pixel Qi's Everywhere Display," *IEEE Spectrum*, January 2010, spectrum.ieee.org/computing/hardware/winner-pixel-qis-everywhere-display.]

Other developers are trying to push LCD technology into a new realm of performance. Reflective displays based on liquid crystals have been around for decades but have so far failed to impress—think of the drab greenish-gray displays on cheap calculators and digital watches. We should be able to do better, and Kent Displays, in Ohio, spun out of the Liquid Crystal Institute at Kent State University, is doing just that. The company's cholesteric liquid crystal molecules have a helical structure (like a spring or DNA). Shine white light on a layer of cholesteric liquid crystal and, in theory, half of the light will have a circular polarization (left or right rotation) that matches up with the liquid crystal. Also, as it travels through the liquid crystal the light encounters a periodically changing refractive index, so in total it can reflect a little less than half the light associated with a certain color. Like regular LCDs, the cholesteric liquid crystal can be reoriented with the voltage so that the reflectance can be switched on or off.

To produce a full-color display, Kent makes three separate primary-color films of liquid crystals, each with its own electrodes and voltage control. Then the company laminates the three liquid crystal films into a single paper-thin sheet. That means each color can seem relatively bright, because the other color sheets can turn transparent when necessary.

Each layer of film is not perfectly efficient, optically speaking, so with three laminated layers the reflectance is about 30 percent—still far from what we'd want for our ideal display a decade from now. Interestingly, Kent has also demonstrated panels with solar cells integrated beneath the display, so its products can satisfy our 2020 requirement of making battery charging an infrequent inconvenience.

These cholesteric displays have potential uses beyond the e-reader of the future. Kent recently demonstrated color-changing e-skins that can conform to a 3-D surface. Just as the iPhone made the keypad disappear, technology like Kent's might make the entire cellphone case a reconfigurable display.

THINK OF THE WINGS of a blue morpho butterfly. Beautiful, eh? That kind of intensity would certainly satisfy our 2020 display criteria. Back in 1996, inspired by those butterfly wings, MIT launched a spin-out company called Iridigm Display Corp. (from *iri*descent reflection and para*digm* shift). Qualcomm MEMS Technologies acquired Iridigm in 2004 and tagged the technology Mirasol.

The display exploits a principle called interferometric modulation. Iridescence, like that on a butterfly, relies on the thickness of a resonant microcavity, the thickness being just a fraction of the wavelength of light to be reflected. The physics are similar to those of the cholesteric liquid crystal but without the strong dependence on polarization. The Mirasol display creates these microcavities using a combination of MEMS mirrors and a stack of thin optical film.

When ambient light hits the structure, the height of the optical microcavity between the MEMS mirrors and the optical film resonates with just a narrow set of wavelengths of light (a single color), and the mirrors reflect only that color. Pixels have preset mirror heights that reflect red, green, and blue light, with multiple mirrors arranged side by side. Apply voltage and the MEMS mirrors move closer to the optical film, the microcavity disappears, and the pixel reflection turns black.

READIUS

DISPLAY
Electrophoretic pixel with plastic electronics
RELEASED
Announced 2008; has yet to ship

SONY READER

DISPLAY
Electrophoretic pixel from E Ink
RELEASED
2006

APPLE iPAD

DISPLAY
LCD
RELEASED
2010 (planned)

This scheme can easily produce a pixel with intense color, but making a pixel that switches between more than two colors is a challenge. In displays, manufacturing has to be ultrasimple to keep costs low. Think about the $200 you pay for a 24-inch LCD monitor; displays, unlike tiny microprocessors, must be really inexpensive per unit of area. Right now, it isn't economically feasible to make MEMS pixels that switch between numerous microcavity heights.

Today these full-color displays reflect about 25 percent of ambient light— much better than full-color electrophoretic displays but not yet approaching our 2020 goal of the 80 percent reflectance of paper. Like electrophoretic displays, they're viewable in sunlight and they're bistable, with the huge power savings advantage that provides; they also can be rapidly refreshed in microseconds, allowing full-motion video. The speed is fast because the mirrors need to move only a very short distance—just hundreds of nanometers.

NATURE HAS OTHER LESSONS for designers of color screens. The adaptive, color-changing skin of chameleons and bobtail squid is biologically complex. But optically, it's easy to understand. The skin contains pigments that concentrate into small dots when the muscle relaxes. Transparent muscle fibers stretch out the skin, thereby enlarging the pigments so that their color becomes visible. When the muscle fibers relax, the pigments spring back into small, barely visible dots.

Conventional printed media exploit a similar principle to mix colors. In theory, a printed image can be made from dots of cyan, yellow, and magenta that overlap to create the full spectrum of color. Using smaller dots, wider spacing between dots, or no dots at all simply permits a brighter, whiter reflection from the paper underneath. (In the real world, black is added in many cases for certain practical reasons.)

In 2006, my team of display researchers began trying to combine those two concepts—the millions-of-years-old biological method of switching pigment and the centuries-old brilliant color capability of printing pigments. Our lab, the Novel Devices Laboratory at the University of Cincinnati, began collaborating with pigment supplier Sun Chemical to try to put modern printing pigments into electrically switchable pixels. We worked at first in electrowetting pixels, a dyed-oil technology now nearing commercialization at Liquavista, a start-up in Eindhoven, Netherlands, backed by venture capital and spun out of Philips Research Labs in 2006. Back at the University of Cincinnati, in 2007 we discovered a new way of building a pixel that uses pigments in water instead of dyes in oil, initially using the same colored fluids found in the cartridges of an inkjet printer. The images produced by this technology look remarkably like printed media.

We called the resulting technology electrofluidic, because the device electrically pulls pigment fluid through microfluidic cavities. The back plate of the display is highly reflective and patterned with an array of tiny holes about 30 µm deep. The holes make up only 5 to 10 percent of the area of the reflective back of the display, so most of the light falling on the display reflects back to the viewer. The front panel of the display is transparent and pressed against the back plate within a space of only about 3 µm. With no voltage, surface tension acts on the pigment fluid to minimize its exposed area, similar to the way a droplet of water favors a spherical geometry. In that state, the pigment fluid rests inside the microscopic holes.

The front and back of the display also include electrodes. Voltage between these electrodes attracts the pigment fluid from the holes and spreads it into the space between the plates. Now most of the colored pigment is visible, filters reflected light, and creates color. Pulling the pigment out of the holes and releasing it back takes only tens of milliseconds, fast enough for video.

In May 2009, the University of Cincinnati spun out a start-up company, Gamma-Dynamics, to bring electrofluidic technology to market; I am the principal scientist. It has several years to go until commercialization. To date, we have demonstrated 1-inch-diagonal arrays of pixels with about 55 percent reflectance. The first commercial electrofluidic displays will likely use a simple pixel filled with black pigment fluid, which can switch the pixel from black to white, overlaid by either a red, green, or blue filter for three out of four subpixels. The fourth subpixel is unfiltered; when it switches to white it simply boosts brightness to about 40 percent.

Even so, this is still only half as bright as the envisioned 2020 e-reader. Electrofluidic technology could potentially allow highly saturated colors and up to 70 percent reflectance if, instead of color filters, the display incorporated multiple holes per pixel, each hole containing a different color fluid. Eventually, they may be bistable and rollable and display video. Electrofluidic displays are the newest player in the color e-reader race, but it typically takes 5 to 10 years to turn a new discovery into a commercial product.

Electrofluidic displays aren't the only latecomer that might make the leap to commercialization before 2020. Consider another: photonic ink. Developed by the University of Toronto spin-out company Opalux, photonic ink creates colorful interference with a stack of precisely spaced nanobeads. A polymer between the beads swells when exposed to electrolytic fluid, altering the optical cavity between the beads and allowing tuning of any color at any pixel in a single layer. It's a very intriguing idea. But the displays built so far aren't very bright, and like many rechargeable batteries, they have limited lifetimes.

WHEN THE ULTIMATE display arrives, the e-reader or roll-up computer will be only one of its many applications. Besides the Kent State technology, which could make the entire casing of an electronic device a reconfigurable display, we'll also see a boom in electronic supermarket shelf labeling. Electronic shelf labels have started to appear in Europe and a few other markets. These labels can reduce a full day's chore of relabeling grocery store shelves into an instant, downloadable activity. It also lets stores adapt pricing to consumer habits in real time—a senior citizen shopping midmorning may get different bargains than those picked up by a professional stopping on the way home from work.

Some of these display technologies may make their way into buildings. E-paper technologies like polymer-dispersed liquid crystals and electrochromic displays are beginning to cross over into "smart" window applications. Windows that shade themselves electronically are already on the market, but smart windows could reflect the infrared portion of the sun in summer and transmit it in winter. This technology may first appear in switchable opaque/transparent glass refrigerator doors, which won't face the potential UV degradation of windows. You'll also see these low-power, high-visibility displays coming into signage and billboards; today's LED billboards use lots of energy. Companies like Israel's Magink are applying cholesteric liquid crystal technology like that used at Kent to large billboards and already have a few in use.

Finally, one more science-fiction fantasy may become reality. Think back to the 1987 movie *Predator*, in which the alien being sweeps through the jungle with perfect color-changing adaptive camouflage armor. The appeal of invisibility, adaptive camouflage, or cloaking never seems to fade. For military applications, the requirements are tough: The green found in plants—chlorophyll—has a complex spectrum that's particularly challenging to reproduce. But there may be a simple answer: Take the complex pigments used in military camouflage and disperse them in the fluid used in an electrofluidic display, and you could create the perfect adaptive camouflage. The truly ultimate display's perfect visibility might have a side benefit—perfect invisibility. ❑

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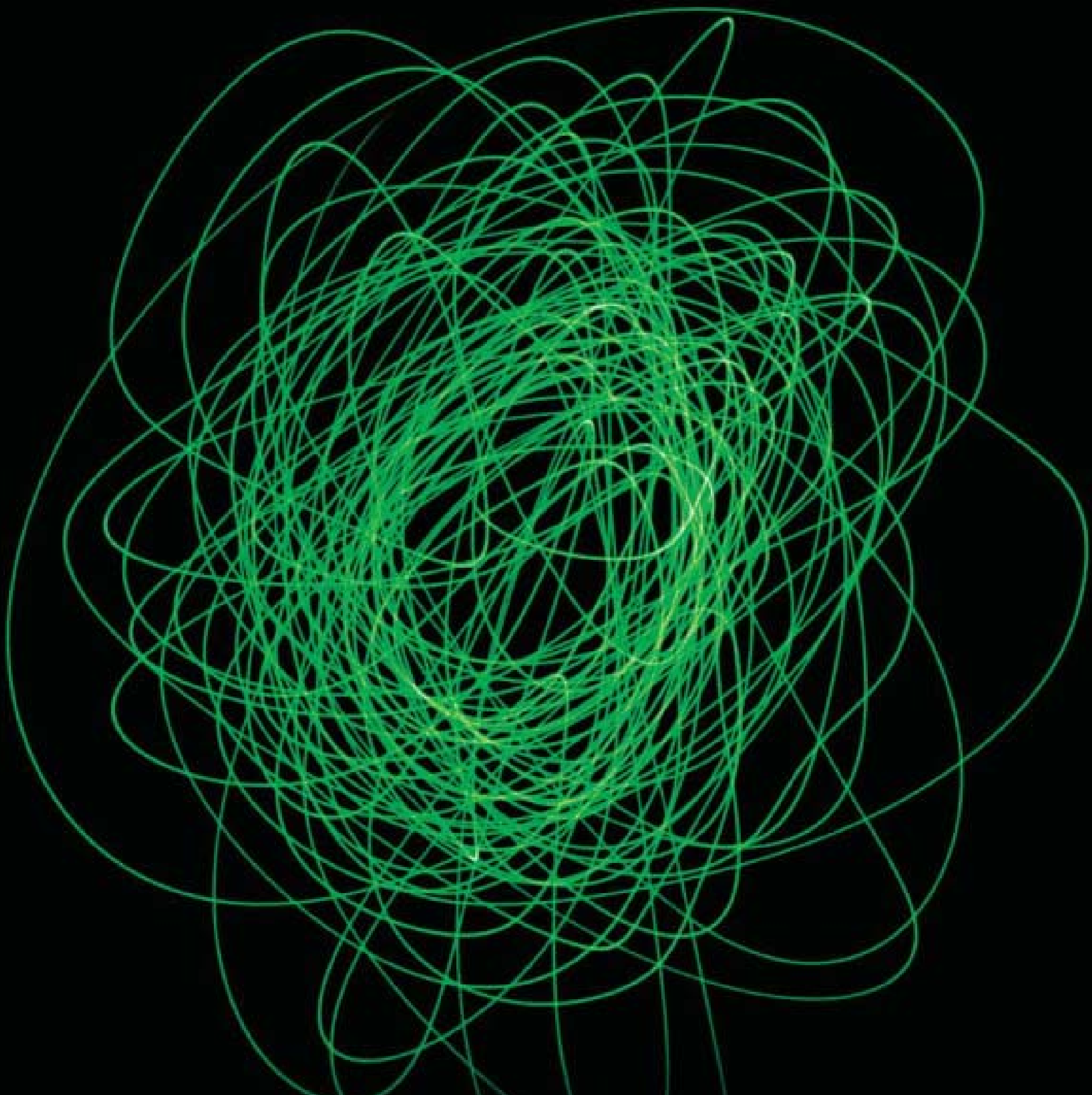
LASERS GET THE GREEN LIGHT

COMPACT GREEN-LIGHT SOURCES COULD SLASH THE COST OF LASER TV

BY RICHARD STEVENSON

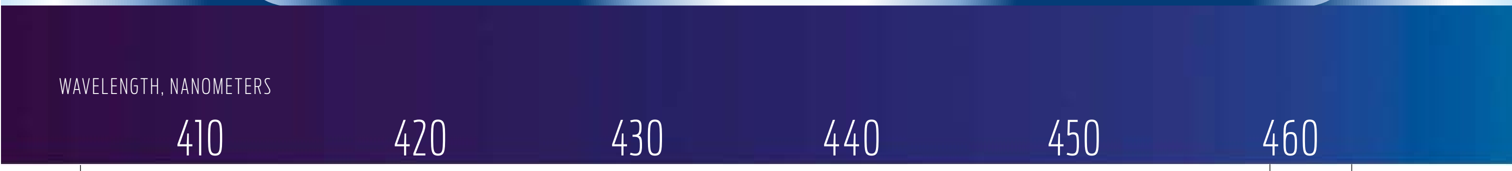


WHAT THE WORLD NEEDS NOW is a semiconductor laser that's good, cheap, long-lasting, powerful, and truly green. Such a device could revolutionize information display, improve certain ophthalmological therapies, and give us affordable televisions with bigger, more dazzling pictures than the best available today.

For display, it would make possible a full-color projector small enough to fit inside a mobile telephone. It may even one day be possible to project ultravivid images directly onto your retina.

It could also cut the cost of a major eye treatment, because green light is ideally suited to burn thousands of spots into the retina, stopping the proliferation of new blood vessels and ameliorating diabetic retinopathy, one of the main causes of blindness in Europe and North America. Green light propagates to greater distances through water than any other color, so it would improve underwater communications. You may also find it in laser light shows, industrial process control, and one day, in DNA sequencing machines.

But the biggest market of all would arguably be for use in television sets. Laser TVs are already available—Mitsubishi began selling a 65-inch model in the United States in 2008, for US $6999. The eye-watering price, which has since dropped hardly at all, reflects the high costs of the green and blue lasers (there's a red one, too, of course, but it's a relatively inexpensive descendant of the semiconductor laser chip in DVD players). The blue is a longer-wavelength sibling of the ultraviolet laser used in Blu-ray players. The real headache, though, is the green laser. Because there is no commercial semiconductor laser chip in this color range, the device's manufacturer had to cobble together a cumbersome contraption known as a frequency doubler. It starts with a laser that emits light at the wavelength of 808 nanometers, in the part of the infrared range just beyond visible red light.



Q1 2007
ROHM PRODUCES A 404-NM NONPOLAR LASER AND ANNOUNCES A PLAN TO BUILD A 532-NM LASER FOR COLOR DISPLAYS.

THE FIRST NONPOLAR LASER IS DEVELOPED AT THE UNIVERSITY OF CALIFORNIA, SANTA BARBARA.

Q4 2007
ROHM UNVEILS A 459-NM NONPOLAR LASER WITH AN INDIUM GALLIUM NITRIDE LAYER.

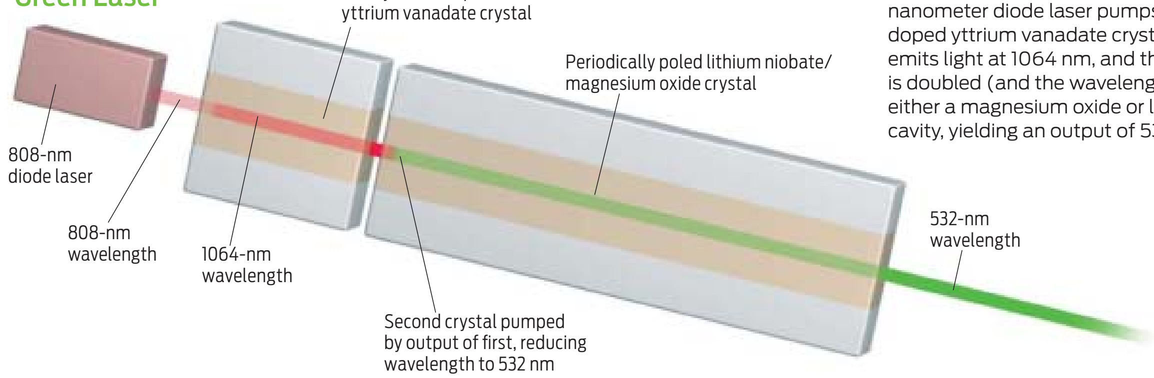
Q1 2008
SHARP CORP. ANNOUNCES A 463-NM NONPOLAR LASER.

That radiation pumps a crystal that emits infrared light at 1064 nm. This light bounces in a cavity between two crystals, doubling the frequency to 532-nm emission. Voilà: green light.

For every watt of light that comes out of the original, infrared laser, you get about 0.4 watt of green light. What's even worse—for a TV manufacturer, at any rate—is that the power and space needs of that green-laser kludge add appreciably to the complexity and cost of the control circuits for the TV.

Since the 1960s, academic and industrial research teams around the globe have been running a race to build the first reliable, manufacturable, green-emitting semiconductor laser. After a flurry of research in the late 1960s and early 1970s ended in failure, practically no one in the field saw that the key to victory was an obscure material called gallium nitride.

Mitsubishi's Laser TV Green Laser



DOUBLE DOWN: Intracavity doubling in Mitsubishi's laser TV begins when an 808-nanometer diode laser pumps a neodymium-doped yttrium vanadate crystal. The crystal emits light at 1064 nm, and then the frequency is doubled (and the wavelength halved) in either a magnesium oxide or lithium niobate cavity, yielding an output of 532 nm.

THE STORY OF THE GREEN laser actually starts with a different color and a different device: LEDs—blue ones.

To understand how and why, you'll need to sit through Lasers 101 (skip this and the next four paragraphs if you've already taken this class). Lasing happens in a semiconducting chip when a free electron skittering through the semiconductor's crystalline lattice drops from a higher to a lower energy band, emitting a photon of a very specific wavelength. As the photon bounces back and forth between the reflective ends of the chip, it stimulates the emission of still more photons of the same wavelength and phase. The resulting cascade of photons wrings energy from the system in the form of coherent, monochromatic light. But such a cascade is possible only if a great fraction of the electrons are in the higher energy band to begin with—an oversupply of "excited" electrons that's called a population inversion. Such an inversion can be obtained in gallium nitride.

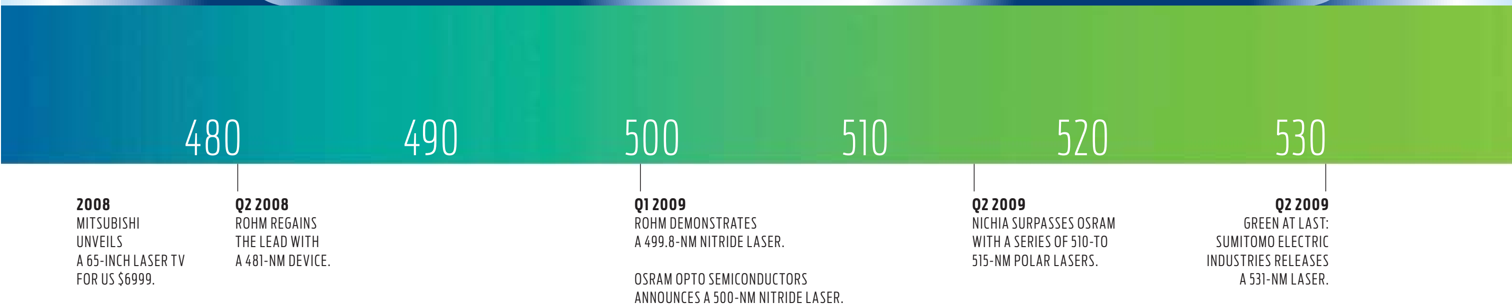
Gallium nitride is a III-V material—that is, its first element, gallium, is in Group III of the periodic table, and its second, nitrogen, is from Group V. The resulting crystal is a semiconductor. If you add just a trace of silicon to the mix, the sprinkling of additional "dopant" atoms will sit on only those sites in the lattice that would normally be occupied by gallium. However, because silicon is from Group IV, each atom contributes an additional, chemically unbound electron to the structure. Such free electrons can move throughout the structure, where together they occupy what's known as the conduction band. Meanwhile, those electrons that are chemically bound end up in the valence band, which has a lower energy. The "energy gap" between the two bands determines how energetic the laser photons will be, and their energy, in turn, determines their wavelength. A high-energy gap means a short wavelength—green, blue, or violet, for example.

Doping gallium nitride with the Group II element magnesium produces the opposite effect, leading to a shortage of electrons needed for bonding. That absence of an electron, called a hole, behaves like a positively charged particle. Holes, too, can move freely throughout the crystal, occupying the valence band.

You can thus engineer gallium-nitride-based structures so that one region has a bounty of electrons—called *n*-type—and another an excess of holes that's called *p*-type. You can then apply a voltage between those two regions to drive the electrons and holes together so that they recombine to emit light. To turn such an emission into coherent laser light, you must make sure that electrons and holes recombine in a confined space, within a reflective cavity, and that enough of the resulting photons linger inside the cavity. Only then can they start a cascade of stimulated emission that produces photons with identical properties.

To maximize the efficiency of a chip laser, specialists engineer into it semiconductor structures that trap electrons and holes in an extremely thin layer, known as a quantum well. Such a well

PREVIOUS PAGE: PHOTO: RYANN COOLEY



is essentially a trench in the center of the device. In a nitride device, the trench is sandwiched by a film of aluminium gallium nitride, and the whole structure is surrounded by cladding—that is, layers having a refractive index higher than the other material. As a result, all the photons are confined between the cladding, in what's called the wave-guiding region, and they can get out only at the ends of the cavity, which reaches to the edges of the laser chip itself. Now you might expect light to pour out at either end, like water from a gutter, but the massive refractive index difference at the semiconductor-air interface ensures that most of the light gets reflected back into the device. There it triggers the release of yet more identical photons. Result: an optical resonator that amplifies light each time it bounces back and forth, until it finally emerges past the interface in all its coherent glory.

In 1993, Shuji Nakamura, a Japanese engineer working alone, came up with improvements in gallium nitride materials science that a year later enabled his employer at the time, the Japanese company Nichia Corp., to release a blue LED with a then-whopping 2.7 percent efficiency. Two years later he fabricated the world's first gallium nitride laser, a device that emitted ultraviolet radiation. To get green light out of a nitride laser, you need to increase the proportion of indium in the device's indium gallium nitride quantum well. Nichia has had substantial success with this approach, and to this day it remains the undisputed world leader in gallium nitride lasers, with efficiencies for some wavelengths exceeding 20 percent.

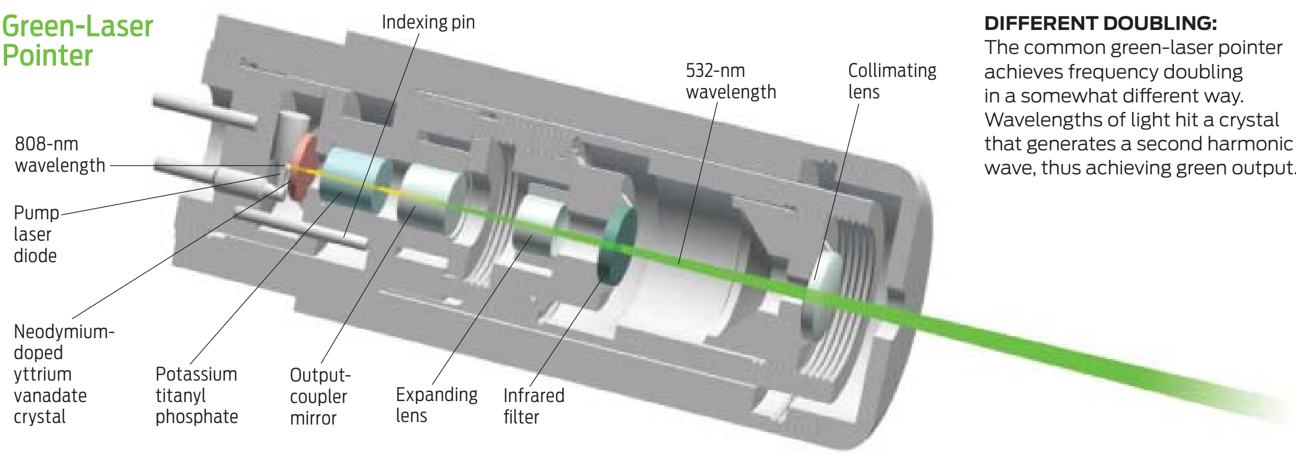
Notoriously secretive, Nichia declined to participate in the reporting for this article. But some of the company's progress can be gleaned from the papers it presents at academic conferences. At first, Nichia reported rapid success in extending its nitride laser emission to blue and beyond. By 2003 the company had produced a 480-nm laser—still blue but at least leaning toward green. Subsequent progress, however, was painfully slow. By 2008 Nichia's researchers had hit 488 nm and commercialized that device, which the company describes as "blue-green."

If you want to get technical about it, 488 nm falls 12 nm short of the line marking the end of the blue range and the beginning of the blue-green. Then you have to go another 20 nm to reach the magic mark of 520 nm, where green light "officially" begins. Although the first 13 years of Nichia's gallium nitride laser development has produced an extension in emission wavelength by 80 nm, it is far from clear if the company will ever find the additional 40 nm needed to make a truly green laser.

The problem of stretching the emission wavelength toward green comes down to a single challenge: increasing the indium content in the quantum well while maintaining the material's quality. These lasers are grown by metal-organic chemical-vapor deposition, which involves heating the substrate and using nozzles to painstakingly inject exact quantities of organic molecules in precise ratios, which then dissociate to release atoms that form the device's crystalline layers. At low temperatures, you get enough indium at the cost of a lot of defects. At higher temperatures, you minimize the defects but get less indium. And the indium atoms that do get in tend to skitter around on the surface, finally clumping together in a way that hampers light emission.

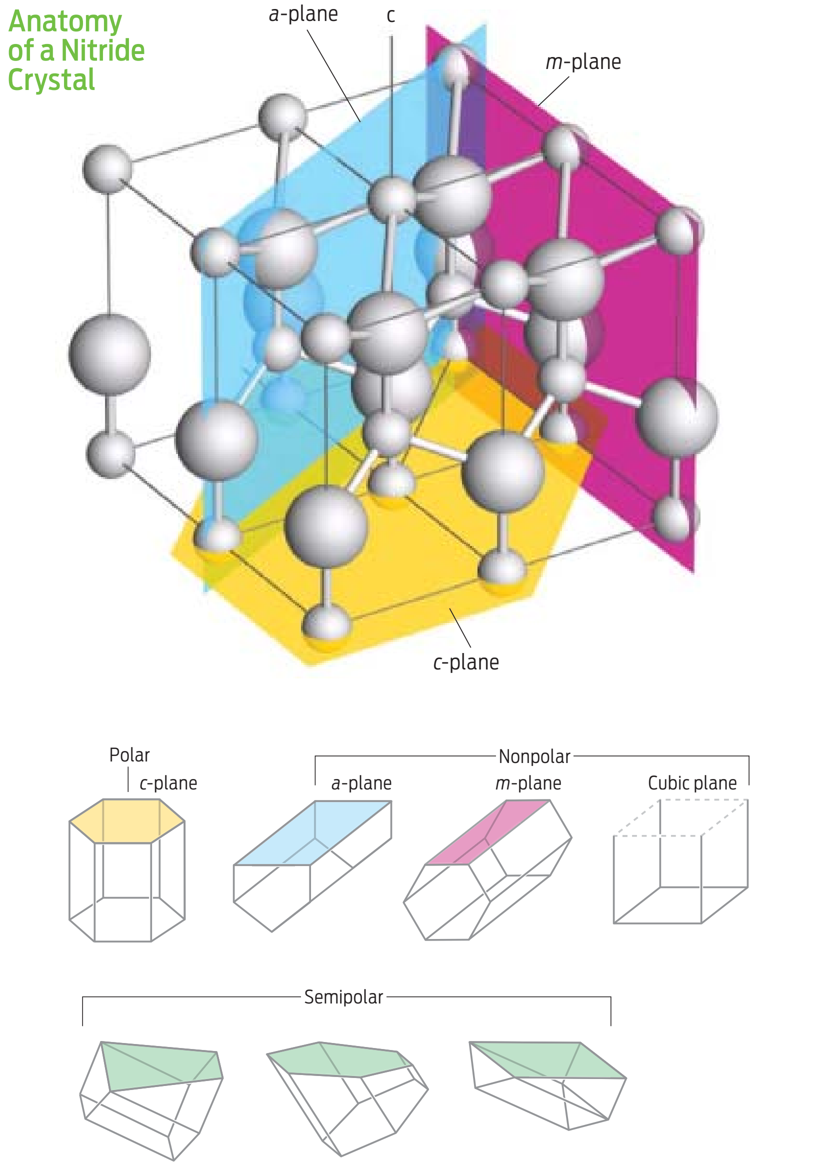
And as if navigating your way through this system of trade-offs weren't bad enough, there's an even tougher problem—known, imposingly enough, as the quantum-confined Stark effect. It stems from the interplay of the electrostatic forces and the internal stresses due to the slightly different spacings of the lattices of gallium nitride and indium gallium nitride. This interplay gives rise to internal electric fields as high as 100 volts per micrometer, enough to cause piles of static charges to form where the quantum well touches the surrounding material. The charges pull electrons to

Green-Laser Pointer



DIFFERENT DOUBLING: The common green-laser pointer achieves frequency doubling in a somewhat different way. Wavelengths of light hit a crystal that generates a second harmonic wave, thus achieving green output.

ALL ILLUSTRATIONS: GEORGE RETSECK



PLANE TALK: Most nitride lasers are grown on the polar plane, which imposes strong internal fields that hamper the electron-hole recombination needed for light emission. Turning to nonpolar planes, such as the *m*-plane and *a*-plane, can eliminate these fields. You can also cut crystals along semipolar planes, creating much weaker internal fields and allowing for a high indium concentration in the active region, which stretches the wavelengths to green.

one side of the quantum well and push holes to the other. That's bad, because it reduces the chances that those charge carriers will recombine to emit light.

Now this separation of charges does have an advantage: It pushes the emission greenward, to longer wavelengths. But this is of little benefit to lasers. Charges at the interfaces make it hard to inject more electrons and holes into the well, and if you try to force those charge carriers through by ramping up the voltage, you'll negate the benefit of the push toward the green. True, those extra charge carriers will set up a field of their own that "screens" the interface charges, making it easier to inject additional carriers into the well. But this screening effect gets you nowhere because it also causes the energy gap between electrons and holes to revert to its original form—and good-bye, longer wavelengths.

THIS WHOLE PROBLEM of internal electric fields can be sidestepped by switching from a crystal grown according to the standard plan to another kind altogether. Any crystal can be sectioned along a given plane, as if you'd passed a thin sheet of paper right through the lattice. Vary the angle of the section and you get different planar arrangements of atomic charges. Once you've cut, sliced, or milled a crystal to expose such a plane—which is like the facet of a cut diamond—you may then grow new crystalline material from that base. Whatever you grow will take on the pattern of that base.

The standard pattern, based on what's known as the polar plane, is plagued by strong electric fields, but there are a number of alternative, nonpolar planes [see diagram, "Anatomy of a Nitride Crystal"]. Their intricacies began to be unraveled only in the 1990s, when David Vanderbilt, a physicist from Rutgers University, in New Jersey, published work on the topic.

It was one thing to grasp the theory of nonpolar electronics, but quite another to find a suitable substrate on which to grow nonpolar crystals. The first breakthrough came in 2000, when Klaus Ploog's group at the Paul Drude Institute, in Berlin, produced nonpolar gallium nitride films. Though Ploog's films depended on exotic materials and therefore couldn't be commercialized, his work encouraged many researchers to start working on other nonpolar films. This included James Speck, a materials specialist at the University of California, Santa Barbara, who teamed up with his colleague Stephen DenBaars. And it wasn't long before Nakamura, who had moved from Nichia to UCSB in 1999, joined them.

Their central challenge was coping with the fundamental stumbling block of all work on gallium nitride semiconductors: the lack of a good platform on which to grow the devices. Like all semiconductor devices, laser diodes are made by taking a substrate—a thin, circular slice of a crystalline material—and piling on a stack of different crystalline layers. You have to make sure that the materials in the substrate and on the layers above have compatible crystalline structures. If they don't, one lattice will stretch or compress the other, and you'll get strains that can fill a growing crystal with defects. Such defects can propagate like a spreading crack, causing the laser to fail after just days or weeks, rather than years.

Of course, you'd have a perfect match if you laid gallium nitride down on a gallium nitride substrate. But it's extremely difficult to make a defect-free gallium nitride substrate (recently, however, a good deal of progress has been made). So for LEDs and lasers researchers have used sapphire as their substrate and found esoteric ways of growing reasonably good nitride crystals on top, despite the mismatch in atomic spacing.

Speck wanted to find a better substrate. He stumbled on the solution in a chance meeting with a representative from NGK Insulators, a Japanese manufacturer of materials for electrical power distribution. The visitor, who was at UCSB primarily to see Nakamura, told Speck that NGK could grow nonpolar aluminum nitride on a plane of sapphire known as the *r*-plane. "I was unaware of this relationship, and I just about came off my chair," says Speck. Armed with this knowledge, his team started using *r*-plane sapphire to develop gallium nitride films. The LEDs that followed were a massive disappointment. Defects plagued the devices, and as a result they had pitifully low efficiencies.

But Speck and his coworkers could not be deterred, thanks to an unshakable belief that the winning orientation for nitrides was the nonpolar one. And success finally came in 2006, thanks to access to very high-quality nonpolar gallium nitride substrates from the Japanese firm Mitsubishi Chemical Corp. These substrates, no bigger than a thumbnail, are the key driver behind a transformation from incredibly dim emitters to those that could compete with the best conventional nitride devices.

LEDs were the first to benefit, with device efficiency rocketing from below half of 1 percent to over 40 percent. A 404-nm laser followed in early 2007; soon after, the university issued a press release to tell the world about the first nonpolar laser.

Three days later the UCSB team had the shock of their lives, when the Japanese electronics company Rohm Co. put out a press release stating that it had also produced a 404-nm nonpolar laser. What's more, Rohm claimed that, unlike UCSB's device, its laser could perform continuously at least as well as conventional commercial equivalents. Details of the UCSB and Rohm devices appeared in the academic press a few weeks later.

No one who read Rohm's press release could be left in any doubt about its plans: It wanted to build a 532-nm laser for color displays, and it hoped to do it by the end of that year. Although it hasn't gotten there yet, the company remains the leading proponent in the push toward nonpolar lasers that emit ever longer wavelengths.

By the end of 2007 Rohm reported a 459-nm nonpolar laser that featured an indium gallium nitride layer that both guided light (a waveguide, that is) and shored up the structure just at the point where it was prone to cracking. At the beginning of 2008, another Japanese laser manufacturer, Sharp Corp., entered the fray with a 463-nm nonpolar laser, but a few months later Rohm was back in front with a 481-nm device. And in February 2009 it snatched Nichia's crown for the longest wavelength nitride laser with a device operating at 499.8 nm.

Just nine days after Rohm reported its latest result in *Applied Physics Letters,* the German electronics company Osram Opto Semiconductors announced the first 500-nm nitride laser in the same journal. This laser, however, employed polar crystals, following Nichia's approach, using the conventional plane. To hit this wavelength, Osram's researchers devoted a substantial effort to optimizing the device structure and the growth processes. "It's not one magic step—it's a lot of small fantastic steps," explains Uwe Strauss, Osram's director of semiconductor laser technology.

Nichia then surpassed Osram in spring 2009 with a series of 510- to 515-nm lasers, also polar. The cause of the success is still secret; Nichia says only that it has improved the material quality of its structure, with particular attention to quantum wells.

THE WINNER OF THE RACE for the first truly green nitride laser emerged on 16 July 2009, when the Japanese tech giant Sumitomo Electric Industries described a device that emits at 531 nm. Green at last! Sumitomo employed neither a polar laser nor a nonpolar one, instead using a halfway house—a semipolar device, built on yet another plane cut through the crystal. Although semipolar lasers do suffer from internal electric fields, the fields are far weaker than those in nonpolar lasers; moreover, semipolar lasers lend themselves more readily to the production of indium-rich quantum wells, which hold the key to reaching longer wavelengths.

So we're in the green, but not yet in the money. To make it into laser television sets, green nitride lasers will need output in the "tens of milliwatts," says David Naranjo, director of product development at Mitsubishi. Today the most powerful long-wavelength laser is a nonpolar device from Rohm that produces a constant output of 92 milliwatts, but its emission is at only 493 nm, a merely bluish green. In comparison, the best results for continuous output from a polar laser come from Nichia's 5-mW device, which emits at 510 to 515 nm; the best results using a semipolar design are produced by Sumitomo's 2.5-mW device, which emits 520 nm. In February, Kaai, a UCSB spin-off founded by Nakamura, Speck, and DenBaars, announced a 525-nm laser; however, it didn't say whether the laser was semipolar or nonpolar.

These devices will also have to demonstrate lifetimes of at least 100 000 hours. So far, companies and academic institutions are closely guarding all information on lifetimes, but Nichia has revealed that its 515-nm, 5-mW laser runs for over 5000 hours.

Manufacturing costs are another serious obstacle. Today it is astronomically expensive to produce nonpolar and semipolar devices, because their gallium nitride substrates are prohibitively costly and typically no bigger than a square centimeter. But Mitsubishi has started trial production of 50-millimeter (2-inch) nonpolar substrates, and it plans a commercial launch in 2010. Should nonpolar substrate costs fall to a level comparable to that of the polar gallium nitride substrates now used for laser manufacture, then nonpolar devices could have the upper hand.

Of course, a key element in unit price is the manufacturing yield. When UCSB's Speck wanted to know how the yield of polar and nonpolar lasers compared, he went to his colleague Matthew Schmidt, a graduate student, who explained that while polar lasers work only occasionally, nonpolar lasers always do. "His answer just converted me for life," says Speck. He adds that nonpolar lasers also give you the possibility of building structures that are far quicker and cheaper to grow. Because the quantum wells can be grown far thicker, they don't require aluminium-based cladding layers, which means that growth times can be slashed from 6 to 8 hours to just 1.

While the details of the winning formula are clearly a big deal for those involved in this research, most of us just want a reliable green nitride laser to see the light of day. When it comes, laser TV prices should tumble, and the technology should find its way into the smaller displays that are common outside the United States. Ultimately this will allow all the readers of *IEEE Spectrum*, wherever they may be, to kick back in their living rooms and watch really colorful TVs. ■

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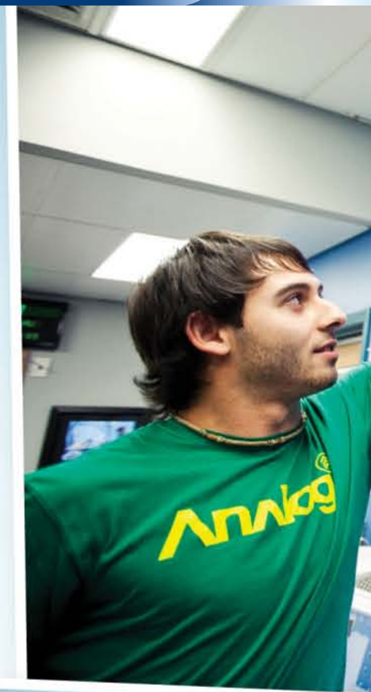
A tiny, remotely piloted sub conquers the raging North Atlantic **BY ARI DANIEL SHAPIRO**

YELLOW SUBMARINE



VARSITY LETTER: Rutgers University scientists dubbed their RU27 robot sub the Scarlet Knight, after their university's mascot. The probe's record-breaking voyage gave both professors and students more cause for celebration than any victory on the playing field.

PHOTOS: MIDDLE ROW RIGHT & BOTTOM ROW CENTER: DAN CROWELL/DEEP EXPLORERS (2); ALL OTHERS: GENE SMIRNOV/ WONDERFUL MACHINE (5)


RUTGERS


R


Last Surfacing
Current Waypoint
RU27

About 48 kilometers off the eastern coast of the United States, scientists from Rutgers, the State University of New Jersey, peered over the side of a small research vessel, the *Arabella*. They had just launched RU27, a 2-meter-long oceanographic probe shaped like a torpedo with wings. Although it sported a bright yellow paint job for good visibility, it was unclear whether anyone would ever see this underwater robot again. Its mission, simply put, was to cross the Atlantic before its batteries gave out.

Unlike other underwater drones, RU27 and its kin are able to travel without the aid of a propeller. Instead, they move up and down through the top 100 to 200 meters of seawater by adjusting their buoyancy while gliding forward using their swept-back wings. With this strategy, they can go a remarkably long way on a remarkably small amount of energy.

When submerged and thus out of radio contact, RU27 steered itself with the aid of sensors that registered depth, heading, and angle from the horizontal. From those inputs, it could "dead reckon" about where it had glided since its last GPS navigational fix: Every 8 hours the probe broke the surface and briefly stuck its tail in the air, which exposed its GPS antenna as well as the antenna of an Iridium satellite modem. This allowed the vehicle to contact its operators, who were located in New Brunswick, N.J., in the Rutgers Coastal Ocean Observation Lab, or COOL Room.

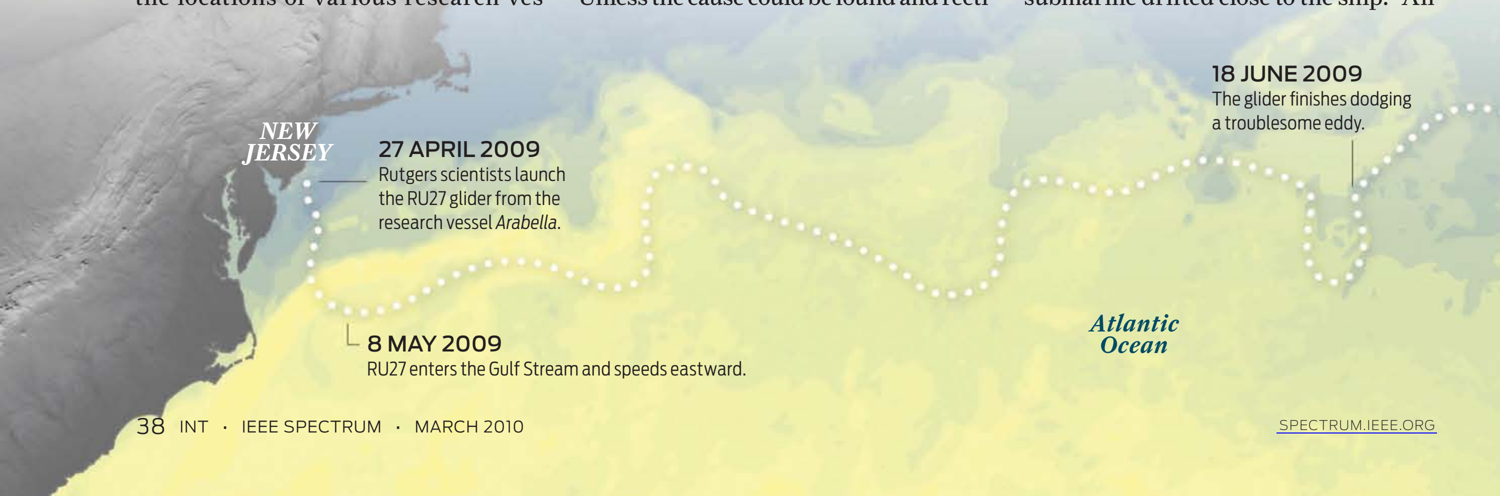
Modeled after NASA's command center in Houston, the COOL Room is lined with computer consoles and plasma displays. They indicate, among other things, the locations of various research vessels and remote-controlled gliders working the world's oceans. Whenever researchers call them up, other nautically relevant charts also dance across the screens, showing, for example, sea-surface temperatures, currents, winds, and cloud cover.

On the day of the launch—27 April 2009—the COOL Room was packed with students, scientists, and technicians, all clinging to the sounds radioed in from the *Arabella*. When Scott Glenn, leader of the shipboard science team, applauded RU27's safe passage into the sea, the throng in the control room followed suit. It was one small step for a machine, on what was to be one giant transatlantic leap for mankind.

But mere minutes into the mission, during an initial test dive, it became clear that something was seriously amiss. RU27 was diving too slowly and ascending too quickly. Had somebody forgotten to install one of the extra battery packs, making the glider more buoyant than expected? Unless the cause could be found and rectified, RU27 would have to be plucked from the Atlantic and returned to Rutgers for disassembly and troubleshooting.

A tense half hour passed while the glider completed another test dive. Finally, the *Arabella* team pinpointed the problem—a hastily mistyped minus sign instead of a plus sign in one of the guidance parameters sent to RU27's onboard computer. "It's nice that it does exactly what it's told, even if it's wrong," Glenn said.

Once that wrinkle was ironed out, researchers in the COOL Room took control of the glider. Tina Haskins, a Rutgers technician who had helped to assemble the glider, surveyed RU27 from the deck of the *Arabella* while the little yellow submarine drifted close to the ship. "All



CHEERY SEND-OFF: The Rutgers team deployed the glider off the coast of New Jersey in late April 2009. Four months would pass before it was seen again.
PHOTOS: GENE SMIRNOV/WONDERFUL MACHINE

right, bid farewell!" she called out. "This is the last time we'll see her on the surface for a while." And with those words still floating in the air, RU27 silently dove beneath the waves.

RU27 IS JUST ONE of more than 100 gliders doing important oceanographic work all over the world. They are designed and built by a handful of companies and research groups. The maker of RU27, Teledyne Webb Research, of East Falmouth, Mass., is the largest supplier of these unique oceanographic robots. Their up-and-down zigzagging lets scientists survey the upper part of the ocean, which is otherwise largely invisible to them.

Satellites track only the sea surface, and most measurements of conditions at depth come from sensors attached to a few thousand floating oceanographic probes that drift wherever the currents take them. To examine targeted areas, oceanographers can lower instruments from research vessels, but such ships have limitations. They cannot be used to investigate the oceanographic effects of violent storms, for example—at least not intentionally. Also, research vessels rarely remain at sea for longer than a month or so at a time, and they're extraordinarily expensive to operate.

Remote-controlled gliders suffer from none of these constraints. They are inexpensive and require no crew or support ship (except while they're being deployed or recovered), making them a cost-effective way to survey large swaths of the upper ocean.

But oceanographic gliders don't just study the sea: Some, known as thermal gliders, can also use the ocean's energy as a source of power. They do so by taking advantage of the temperature difference between the surface, which is warmed by the sun, and the ocean's chilly depths.

To understand how a thermal glider works, imagine for a moment that you've filled a garbage bag with tap water and then frozen the entire mass. Next, you attach a good-size lead sinker to it and plop it into the ocean. After bobbing around on the surface for a while, the ice would melt, and the weighted bag would sink. Now, consider what would happen if the seawater surrounding the sinking mass became cold enough to freeze the water in the bag. Ice would re-form, and the bag would float to the surface, lead sinker and all, whereupon the cycle would start all over again. If this contraption had wings, it could also glide forward as it yo-yoed up and down.

This little thought experiment is a radical simplification of how a thermal glider actually works. Real thermal gliders don't contain bags of ice; they use a substance that changes from solid to liquid at a higher temperature. And they employ a complex arrangement of internal reservoirs, bladders, and gas chambers to adjust their buoyancy. It's a clever way to tap nature's energy at sea, but the technology is still in its infancy. Teledyne Webb Research has built only a half-dozen thermal gliders, some of which are now undergoing sea trials.

RU27 uses a simpler system—an electrically operated piston, which displaces a small amount of seawater to adjust the sub's buoyancy. Other electric gliders adjust their buoyancy using a motor to pump oil in and out of a seawater-displacing bladder [see illustration, "Electric vs. Thermal Gliders"]. This doesn't allow for the kind of multiyear operations that are envisioned for thermal gliders. But even so, the

ILLUSTRATION: EMILY COOPER

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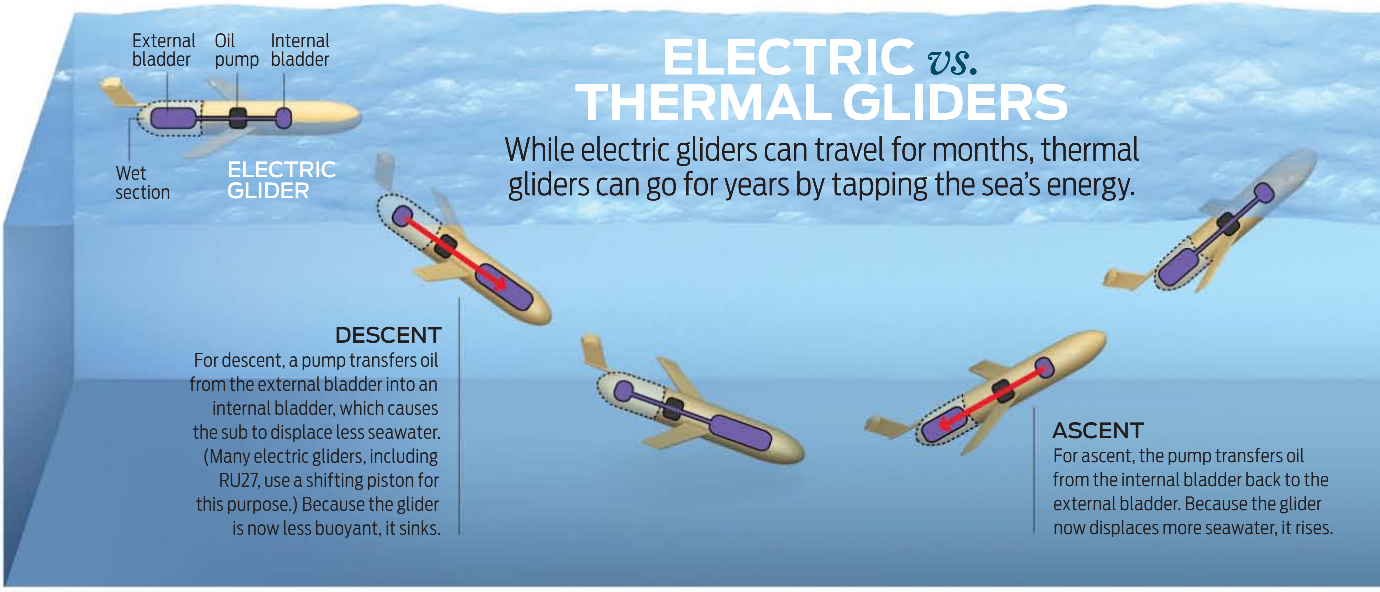


ILLUSTRATION: EMILY COOPER

Rutgers oceanographers calculate that their electric gliders are something like a thousand times as efficient as a typical automobile in terms of energy expended for each kilometer traveled.

As these gliders move, they use thermistors to measure the temperature of the sea around them and conductivity sensors to gauge how salty the water is. These readings help oceanographers determine how the upper portion of the sea stores heat and moves that heat around, which plays into discussions about global climate change.

A glider's payload bay can be crammed with other sorts of scientific instrumentation as well—optical sensors for measuring water clarity and the density of microscopic plants called phytoplankton, hydrophones for recording whale vocalizations and other sounds of the sea, and chemical sensors for tracking dissolved nutrients, to name but a few examples. All this information is relayed in near real time to scientists, who can use it to refine computer models of oceanic circulation and to decide where the glider will go next.

When it comes to monitoring the ocean, then, these little robotic subs can pack quite a punch, which is why the data they transmit are so valuable and why a glider's long-term survival is so important—and not to be taken for granted.

The Rutgers team learned this the hard way a year earlier when RU17, a different glider with the same transatlantic mission, "died a hero's death," as Oscar Schofield, a Rutgers oceanographer, put it. RU17 foundered just off Portugal's Azores islands, more than 3000 km from its point of origin. It might have sprung a leak, or one too many remoras (a kind of suckerfish) may have attached themselves to the glider and weighed it down. Whatever the reason, when RU17 sank, so did the spirits of the team that had assembled and piloted it, making them even more tense during this second try.

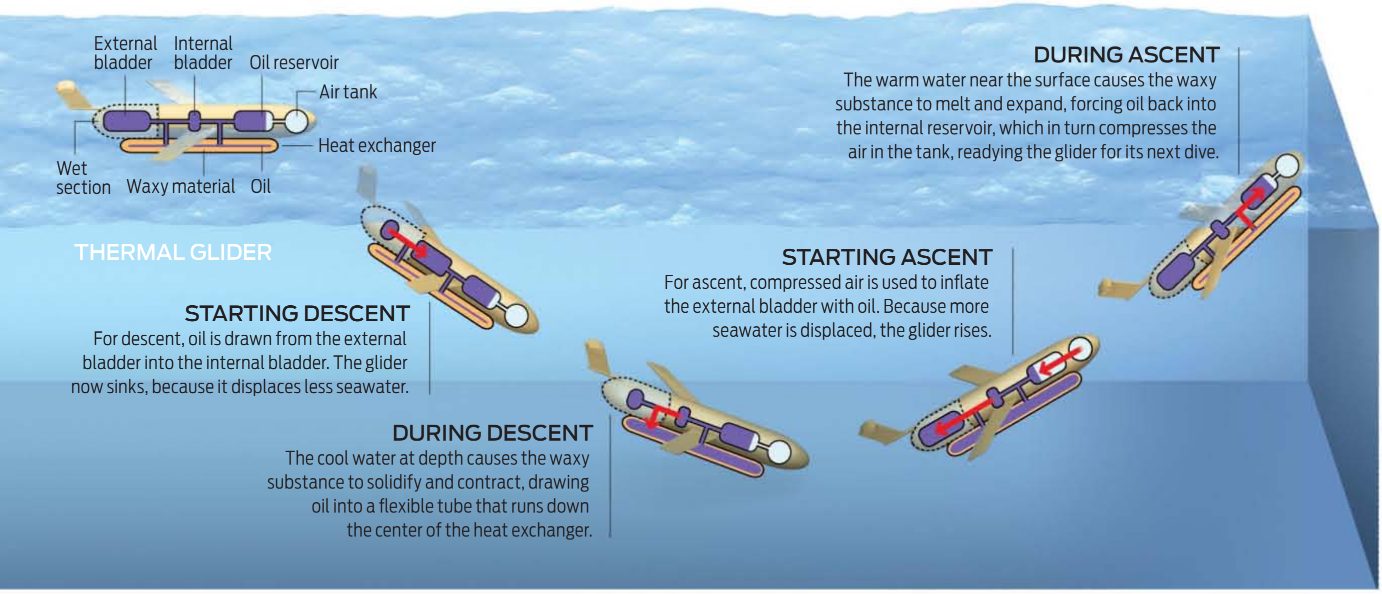
CHILLY RECOVERY: The sea was uncharacteristically calm on the cold December morning that scientists brought the glider aboard the Spanish ship *Investigador*.

PHOTOS: LEFT: DAN CROWELL/DEEP EXPLORERS; RIGHT: GENE SMIRNOV/WONDERFUL MACHINE

Each month of RU27's journey supplied a fresh batch of maritime adventures. Schofield said that waiting for the glider's regular satellite calls was like waiting for one of his teenage daughters to phone home and check in. Each time the glider failed to ring the COOL Room on schedule, the team fretted as if for a lost child, poring over logs and command histories until the scientists finally got the call they'd been anticipating.

One early goal of the mission was to have RU27 hitch a ride on the Gulf Stream, a fast-moving current that originates in the Gulf of Mexico and travels partway up the East Coast of the United States before shooting directly toward the other side of the Atlantic. To reach these quick-moving waters, the team planned to take advantage of warm-core rings, large masses of warm water swirling around in the otherwise cold seas north of the Gulf Stream. The idea was to steer RU27 into such a ring, where it would be swept along on a circular course toward the fast eastward flow. That was the plan, anyway. But by the time the researchers were ready to put it into action, there were no rings to be found. Instead, the scientists had to rely on currents of a much smaller scale, which were harder to navigate. But finally, the controllers managed to get the glider into the Gulf Stream, which sent it clipping along at 7 km per hour, seven times as swiftly as it could travel by itself.

Haskins claims that each of the gliders she works with has its own personality, noting that RU27 "seems so much faster and more agile than our other



gliders, [allowing it] to use currents more favorably." Yet by late August, after coasting with the Gulf Stream and then maneuvering through weaker seas, RU27 began to seem awfully slow. The glider was nearing the Azores, and the team dreaded a repeat of RU17's demise. Something had to be done. So Haskins and two other technicians flew to the Azores to find out what was wrong.

They spent five days aboard a hastily chartered boat and traveled more than 300 km out to sea searching for RU27. Once they located the glider, Haskins and her colleagues jumped into the water to examine it. Understandably, they didn't want to bring it aboard the ship, which would have turned the transatlantic trek into two less-than-record-breaking legs. But they didn't have to. Haskins discovered that the seams in the glider's hull were covered with hundreds of gooseneck barnacles. Their extra drag had slowed the glider and made it hard for it to maneuver. Haskins and her coworkers removed the barnacles, and before long the glider was again winging its way toward Spain.

Although the Rutgers researchers used RU27 to collect oceanographic data, their primary motivation for the mission wasn't scientific. Rather, they wanted to test the machine's limits, garner publicity, and generate goodwill for the kind of work the scientists are doing. If pure oceanographic research had been their objective, they wouldn't have made certain sacrifices to complete the long voyage, replacing many of the usual sensors with extra battery packs and limiting data collection to just 1 hour a day to conserve energy.

Because undergraduates had been so involved in piloting the submarine, it's fair to say that RU27 served more as a teaching aid than as a research tool. The vessel also became something of a transatlantic emissary. In addition to its many extra batteries, it carried 200 letters written by schoolchildren from all over the United States. The idea was that those letters would be given to Spanish schoolchildren who would then become the Americans' pen pals.

RU27 would solidify some links between grown-ups, too. On the second half of the voyage, Rutgers scientists began relying on Spanish colleagues at the University of Las Palmas, in the Canary Islands, for oceanographic data to help guide the glider through the eastern half of the Atlantic. Scientists at the University of the Azores helped, too, as did oceanographers working with the Spanish Port System. So in early December 2009, when Glenn met with some of his Spanish colleagues for the first time to coordinate the recovery of the glider, he felt as though he were seeing old friends.

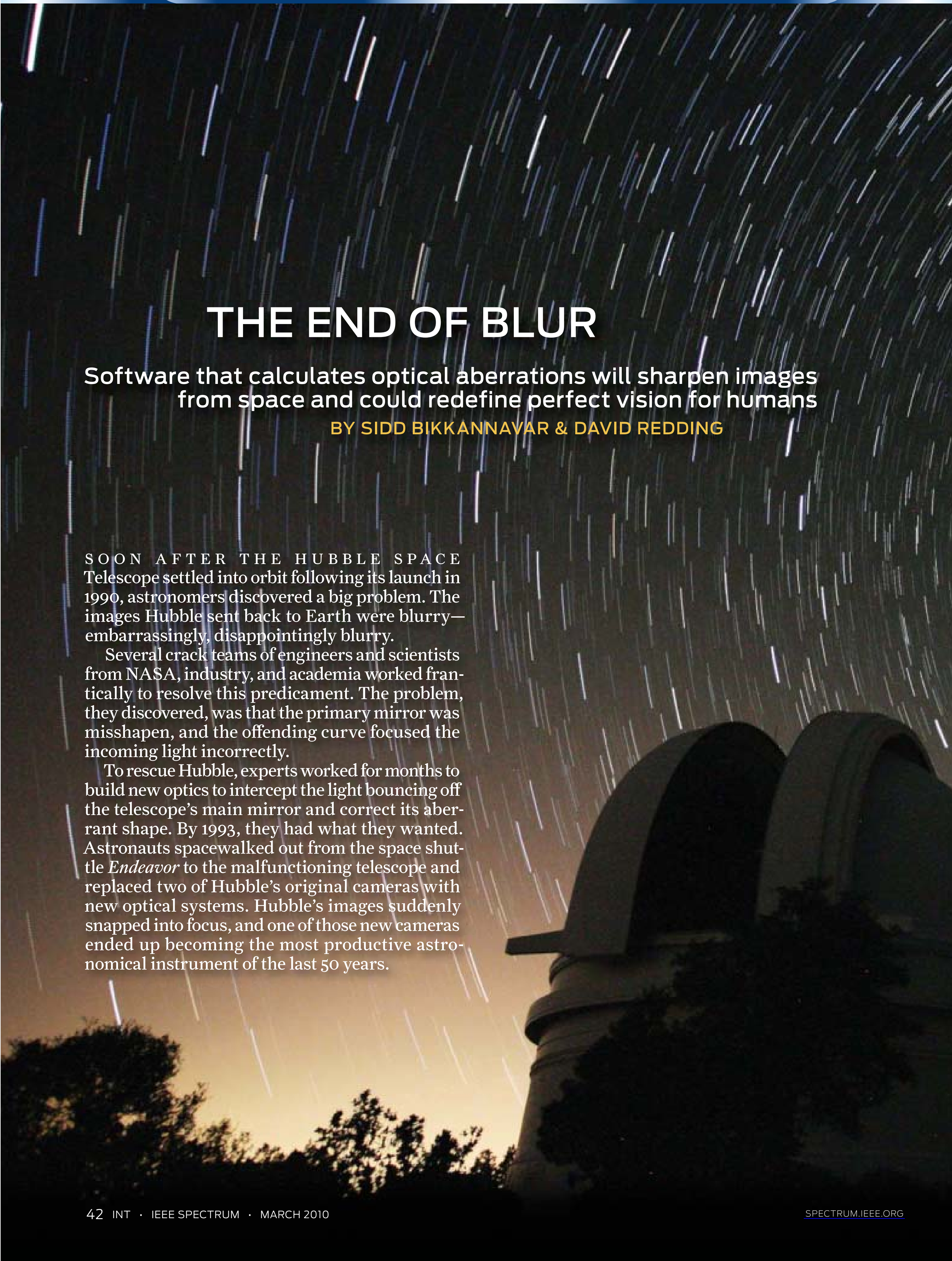
On 3 December 2009, Glenn, a handful of others from Rutgers, and Clayton Jones, senior director of glider development at Teledyne Webb Research, boarded the research vessel *Investigador*, which left the Spanish port of Vigo and within 20 hours maneuvered to within just a few kilometers of the heroic little sub. The night was pitch black, and the seas were calm.

Back in New Jersey, the COOL Room wasn't nearly as placid—indeed, it looked like the site of a science slumber party. The Rutgers oceanographers, their students, and various other hangers-on were killing time gabbing about oceanography while chomping on bananas and chocolate doughnuts. Everyone was staying up late to learn more about the glider, which had already caused a good number of sleepless nights.

At 3:13 a.m., the speakerphone in the COOL Room crackled to life: On the Spanish ship, Glenn announced that they'd spotted the glider. After hauling it aboard a small inflatable skiff, they gingerly hoisted the boat and glider onto the *Investigador*. Raucous applause erupted in the COOL Room as backs were patted and high fives given, rivaling the fervor displayed at mission control in Houston during an Apollo-era splashdown.

As with those moon missions, not all that much science had been done. Still, the little glider had just made history: It was the first remote-controlled object to cross an ocean underwater—admittedly, with a barnacle-cleaning pit stop along the way. The little robot's 221-day voyage had taken it 5300 km as the crow flies. So it was time for the Rutgers scientists to celebrate. The festivities were just as lively off the coast of Spain aboard the *Investigador*, where RU27 soon found itself dripping wet again, this time not with seawater but with champagne. ❑

TO PROBE FURTHER Interested readers can find an audio slideshow on RU27's voyage at http://spectrum.ieee.org/glider-slideshow.



THE END OF BLUR

Software that calculates optical aberrations will sharpen images from space and could redefine perfect vision for humans

BY SIDD BIKKANNAVAR & DAVID REDDING

SOON AFTER THE HUBBLE SPACE Telescope settled into orbit following its launch in 1990, astronomers discovered a big problem. The images Hubble sent back to Earth were blurry—embarrassingly, disappointingly blurry.

Several crack teams of engineers and scientists from NASA, industry, and academia worked frantically to resolve this predicament. The problem, they discovered, was that the primary mirror was misshapen, and the offending curve focused the incoming light incorrectly.

To rescue Hubble, experts worked for months to build new optics to intercept the light bouncing off the telescope's main mirror and correct its aberrant shape. By 1993, they had what they wanted. Astronauts spacewalked out from the space shuttle *Endeavor* to the malfunctioning telescope and replaced two of Hubble's original cameras with new optical systems. Hubble's images suddenly snapped into focus, and one of those new cameras ended up becoming the most productive astronomical instrument of the last 50 years.

NIGHT VISION: Earth's rotation produced these star trails behind Palomar Observatory's Hale Telescope.
PHOTO: PALOMAR OBSERVATORY

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STAR POWER: Hale Telescope, at Palomar Observatory, has a 5.1-meter primary mirror.
PHOTO: PALOMAR OBSERVATORY

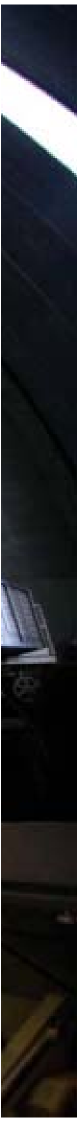
What started out as NASA's greatest embarrassment set in motion a new wave of optics research with broad implications for astronomy and vision science. It took NASA three years, a space shuttle launch, and US $700 million to fix Hubble. We're hoping to eliminate all that trouble for future telescopes by measuring and analyzing blur in real time, using just the data in an image.

In our work at the Jet Propulsion Laboratory (JPL) at Caltech, in Pasadena, Calif., under a contract with NASA, we have built software to help us fix all kinds of blur, including but not limited to the type that afflicted Hubble.

The general idea is simple. We're taking advantage of the fact that our future telescopes will include flexible mirrors that bend and move upon command. By understanding the deficiencies in an image, we can compensate for them by remote control—no astronauts needed. The power of this method lies in its ability to use an optical system's existing camera as a sensor to detect its own error, without installing any separate devices. This software-based approach has already extended our telescopes' ability to peer into the darkness of the universe. On Earth, we believe the software could enable vision scientists to enhance human eyesight beyond "perfect" 20/20 vision, opening up the possibility of "superhuman" vision.

Most adults don't have 20/20 vision. Imperfect vision is caused by aberrations in the way the lens of the eye transmits light to the retina. Those deviations occur in an important aspect of light called the wavefront, a set of points that are all in the same phase. You might be familiar with the term from ads for LASIK eye surgery. The vision-correcting procedure uses a beam of laser light that penetrates the eye, reflects off the retina, and travels back through the eye, capturing and mapping the errors in the way the wavefront strikes the eye.

What causes the wavefront to become distorted? Objects emit or reflect light in spherical waves. Our eyes intercept a small portion of that wave surface, and at great distances this surface is considered basically flat. To form a perfect image on your retina, your eye forces these flat waves to curve inward, so that the waves converge at one point on the focal plane behind your eye's lens. If the converging waves are not perfectly curved, not all of the light will come into focus at a single point on your retina. The result is a blurry or distorted image. All the points of deviation from the perfect spherical wave shape are called wavefront error. Plotted on a 2-D map, the error would look like mountainous terrain, with peaks and valleys corresponding to each deviation from the ideal flat surface.

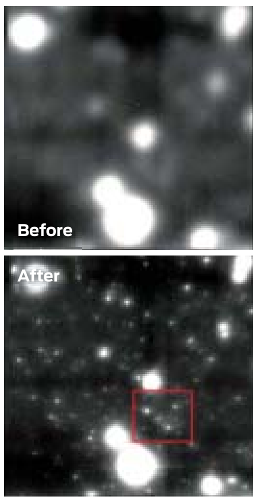


HUBBLE'S NEW EYES

New optics finally let the space telescope see the universe.

M13 GLOBULAR CLUSTER

Adaptive optics let Palomar Observatory create sharper images than Hubble could.



MESSIER 100 GALAXY

Hubble's corrective optics cleared up this image of a remote spiral galaxy.

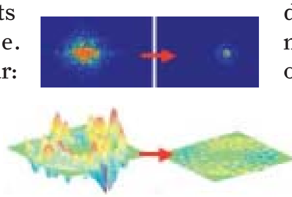
CAT'S-EYE NEBULA

Wavefront-correcting software at Palomar fixed the blur caused by Earth's atmosphere.

NEW EYES AND MESSIER 100: ESA HUBBLE SPACE TELESCOPE/NASA (4); M13 AND CAT'S-EYE: CALTECH/JPL/CAMBRIDGE/PALOMAR OBSERVATORY (4)

The aperture of a telescope works much the same way as your eye, and the causes and fixes for blurry images are also similar. If we know the shape of the wavefront error, we can manufacture an optic with the opposite shape and cancel the imperfections. Scientists did just that for Hubble. LASIK operations are similar: Ophthalmologists calculate the opposite pattern of the aberrant light, and then lasers carve that shape into the cornea. It sounds gruesome, but it works.

A more exciting application is to alter the shape of a flexible lens or mirror to fine-tune the optical system on the fly. The next generation of space telescopes will be equipped with changeable or "active" optics, and many existing observatories on the ground have already upgraded the rigid, fixed optical systems of the past. The main feature is a deformable mirror, which is a thin, reflective surface that can be made from a variety of materials, including glass, beryllium, molybdenum, and composites. The mirror is mounted on a grid of actuators that are lined up like a bed of nails. By moving these actuators, we can morph the mirror to cancel the wavefront error exactly and produce a clear, sharp image. When tackling the rapidly changing wavefront error caused by turbulence in the atmosphere, we can even take the "twinkle" out of stars.



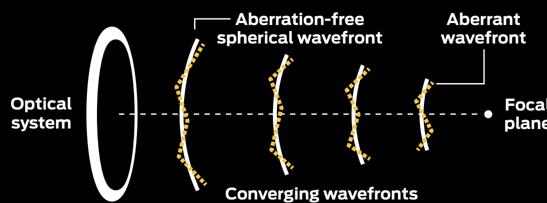
WAVEFRONT WIPEOUT: A map of the wavefront's deviation becomes flat, and a sharper image [top] is produced. *IMAGES: SIDD BIKKANNAVAR/JPL*

The foundation for this wavefront-sensing technique emerged in 1904, when astrophysicist Johannes Hartmann mounted a giant screen across the aperture of the telescope at the Great Refractor observatory, in Potsdam, Germany. The screen was punctured with several holes. Light rays passing through each hole hit photographic plates both before and after they came into focus, producing two spot diagrams. Because he knew the distance between the two plates, Hartmann could determine the locations where these bundles of rays came into focus. This gave Hartmann a basic estimate of the aberrations in the telescope's primary lens.

Astronomers working on large telescopes used Hartmann's technique for more than 60 years. Then, in the late 1960s, the U.S. Air Force became interested in using ground-based telescopes to keep watch over satellites in orbit. They wanted to improve the images of satellites by simultaneously measuring the wavefront. But satellites are dim to begin with, and most of the light coming into

A Brief History of Wavefront Error

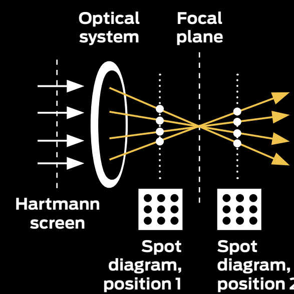
Aberrations in the curvature of a lens or mirror can cause telescopes in space and on the ground to suffer from blurry vision. Here's how to fix it.



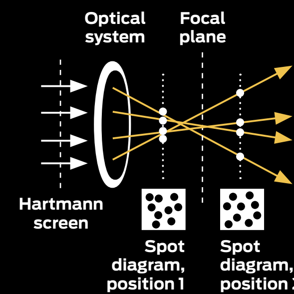
1904

HARTMANN SCREEN TEST

Johannes Hartmann uses a perforated screen to test a telescope's optics. Light passes through its holes, producing spots on photographic plates in front of and behind the focal plane.



In a good system, the rays connecting two spots all pass through the focal plane at one point.



Poor optics send rays across the focal plane at many different locations.

the telescope was needed just to produce a basic image of the satellite. That posed a problem for the Hartmann screen, which blocks most of the incident light to produce the separate ray bundles.

Roland Shack, at the University of Arizona Optical Sciences Center, in Tucson, figured out a way to replace the Hartmann screen with a grid of tiny lenses, or lenslets, that could capture all the incoming light. He used a beam splitter to allow some of the incident light to pass through to the imaging camera and redirected the rest of the light to a new wavefront sensor. The lenslets focused light into hundreds or even thousands of tiny spots on the semiconductor photodetector arrays of a charge-coupled device camera. A flat, undistorted wavefront would form spots in a perfect grid pattern, but a distorted wavefront would result in a distorted grid. By examining how the erroneous spots deviated from the ideal, Shack could reconstruct a model of the wavefront error. Adding more lenslets to the array produced more spots, which led to more precise estimates of the error. On the other hand, using fewer lenslets allowed the wavefront to be computed more rapidly—fast enough to keep up with the atmospheric turbulence that ground-based observatories must contend with.

Versions of the Shack-Hartmann sensor are now used in the adaptive optics systems of most advanced telescopes. The results can be extraordinary. In the summer of 2007, astronomers at Palomar Observatory, in California, used an adaptive optics system built by our group to create the highest-resolution direct images of space ever recorded in visible light. Using a Shack-Hartmann wavefront sensor, a deformable mirror, and a camera called LuckyCam, built by the Institute of Astronomy in Cambridge, England, the astronomers captured images of the M13 globular cluster, about 25 100 light-years from Earth, that were twice the resolution of what Hubble can produce. In other words, a ground-based observatory outperformed its space-based cousin—an astonishing feat considering the significant distortions created by Earth's atmosphere. The combination of these technologies was named one of *Time* magazine's Best Inventions of 2007.

The Shack-Hartmann wavefront sensor isn't perfect, however. Its hardware introduces small flaws into the error measurement, and the number of lenslets in the sensor limits its resolution. A better approach is to measure the error right where a camera perceives it, without introducing extra equipment. For the slowly changing wavefront error that telescopes experience in space, we can do this, and at a much higher resolution than the Shack-Hartmann sensor can.

Let's say you're observing a certain star. No matter how perfect the optical system—be it a ground-based observatory, a space telescope, or the human eye—the optics will distort the light in some way, which degrades the image. But that degradation is also a signature imprinted on the image. We can decode that signature to reveal the shape of the wavefront error. This is the function of our software—it processes images to decode the underlying wavefront errors.

Light is an electromagnetic wave, so it has both an amplitude, which we see as the intensity of light, and a phase, which neither our eyes nor a camera can see directly. We want to detect the phase because it's essentially equal to the wavefront error. We'd like to detect it at a particular location, namely at the aperture of the telescope, which is located at the large primary mirror. To do so we must use an indirect "phase retrieval" method, where we process image data together with a computational model of the optical system. Engineers Ralph Gerchberg and W. Owen Saxton proposed this technique in the 1970s while working on electron microscopes.

Phase retrieval begins with the shape of the telescope's aperture, which sets the parameters for our solution. We set the amplitude to match this aperture shape, and we set the phase randomly. Then we turn to our computational model, which calculates how a wave moves between the aperture and the image plane of an optical system.

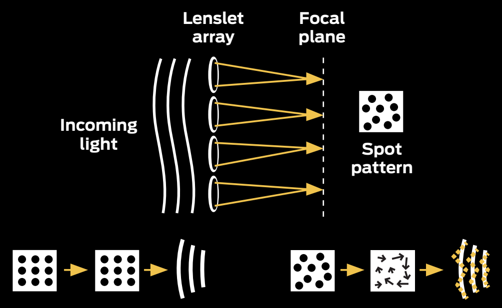
The model sends the phase and amplitude information through the optical system to the image plane, where the camera resides. This transformation adjusts the values of the amplitude and phase to correspond with the new plane. Then we use a real image, taken by the camera, and replace the old amplitude with a new value from that image.

NASA

1960s

SHACK-HARTMANN WAVEFRONT SENSING

Roland Shack introduces an array of small lenses focused on a light sensor. Light passes through the lenslets and produces a spot pattern on the sensor.



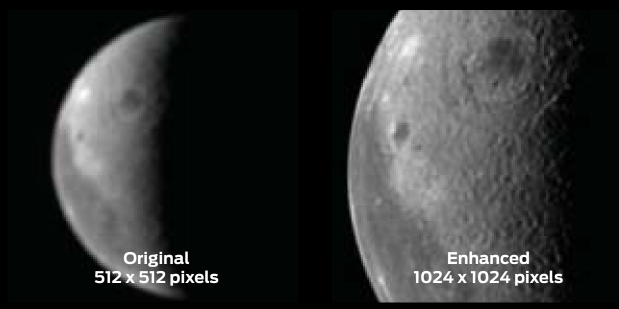
In a perfect optical system, the spots form a perfect grid. There's no wavefront error.

With flawed optics, spots deviate from the grid. Each spot's distance from the grid reveals the error.

2000s

MODIFIED GERCHBERG-SAXTON ALGORITHM

Software replaces or assists a telescope's wavefront-sensing hardware by deriving error from image data.



Correcting for wavefront error, using calculations from image data and a computer model of the optics, refined this picture of Earth's moon from NASA's Deep Impact mission.

DEEP IMPACT/NASA

Next, we use the model in reverse, to send the light back to the aperture. Once again, we use the aperture to constrain the result, giving us a new estimate of the phase. This basic algorithm is repeated until the image generated by the computer model agrees with the measured data from the aperture.

The method generates wavefront estimates that are consistent with a single image, but it does not resolve all ambiguities. Worse, it fails completely if the wavefront error exceeds the wavelength of light. To fix those shortcomings, we must process multiple images at the same time. The Hubble analysis of the early 1990s incorporated this realization, and we've been working on this problem ever since.

Our software runs multiple loops, each processing one of many images taken at different focus settings. The results from all these loops are combined to create a joint estimate of the wavefront error. We then run all those loops again, this time using the joint estimate to set the starting phase for each loop. We repeat the operation until the joint estimate converges on a single wavefront estimate.

Our main innovation at JPL was to improve the model of the true optical system while it was running. This has allowed us to compensate for one of the original method's main failings. Recall that a perfect wavefront is essentially flat, and an aberrant wavefront has high peaks and deep valleys. As we mentioned earlier, if the length of a peak or valley exceeds the wavelength of light, the Gerchberg-Saxton algorithm breaks down. Now we have a workaround. Early runs of our algorithm provide guesses as to what is really happening in these problem spots, and we can use that information to guide the solution.

By adapting our optical model, we can also reduce inconsistencies in the data. What if the telescope moved while taking some of the images? Or what if the focus changed? The software tracks these things and puts them in the model. With each iteration of the algorithm, the model updates and improves—and the wavefront-error solution becomes more accurate. To see just how accurate it has become, consider that the test mirror that caused Hubble's problems was misaligned by just the thickness of a human hair. Using our algorithms, we've demonstrated wavefront-sensing accuracy to 2 billionths of a human hair.

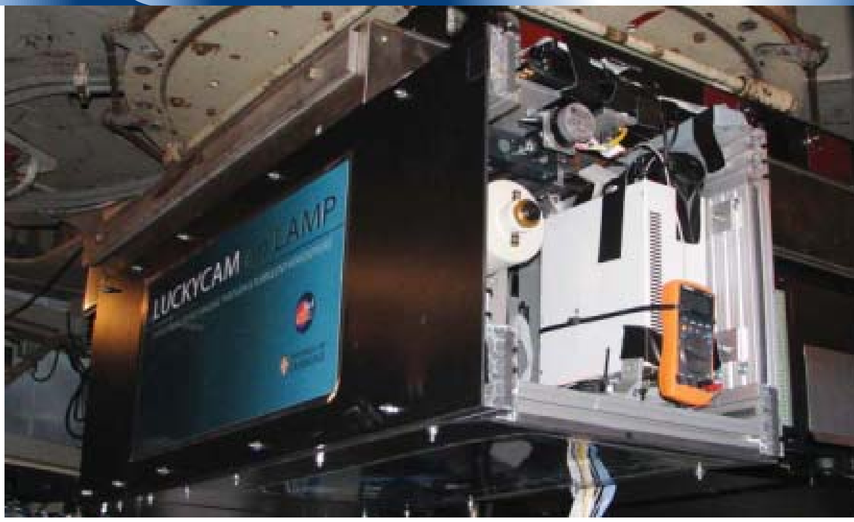
The major benefit of our software, called the modified Gerchberg-Saxton algorithm, is that it can work with almost any type of optical hardware or deformable mirror. If an observatory has only a single mechanically movable lens, the software will calculate how the lens's position must change to best focus the final image. If a more sophisticated deformable mirror is in place, the algorithm can determine the precise voltages needed to adjust the mirror's actuators.

To train the software to make those corrections, we must toggle each of the optical system's movable components by a small amount. The software measures how each movement affects the wavefront error. It then reverses the error to find the precise movements necessary to create the ideal wavefront shape for that particular optical system.

The software has already contributed to science at Palomar, where it is now used with the observatory's existing adaptive-optics system. Researchers have also begun to apply this technique to a wide range of endeavors in space science.

Let's say you're peering through a telescope in search of undiscovered planets. One challenge is that the brightness of a star may obscure interesting objects near it. But if you can alter the shape of the wavefront, you can in effect redistribute the stellar light away from the orbiting companion, without blocking, filtering, or otherwise losing any of the light. Two exoplanet astronomers at Palomar Observatory have begun testing this light-altering technique to image candidate stars in search of faint companions.

Our wavefront-sensing algorithm has another valuable feature. In the previous example, we described how the technique can change the optics before an image is made. But we can also use it to fix existing blurry pictures. The estimate the algorithm produces can be transformed to what's called a point-spread function, which tells us how the error creates blur around a perfect point of light. We can plug this information into a number of advanced image-processing techniques to achieve "superresolution" in an image. Superresolution refers to the ability to obtain information beyond what was recorded by a camera—in other



SHARP SHOOTER: The high-speed LuckyCam uses adaptive-optics software to beat atmospheric blur. *PHOTO: PALOMAR OBSERVATORY*

words, the algorithm can help us restore image data that was lost by a camera's imperfect optical system.

We tried out this application with data from NASA's Deep Impact mission, launched in 2005, which sent a probe to crash into a comet named 9P/Tempel to stir up dust for astronomers to observe. As the probe journeyed through space, its science team discovered that the spacecraft's high-resolution imager was out of focus. On a whim, we asked the researchers for the data from a picture taken before the impact. We used the modified Gerchberg-Saxton algorithm to calculate the imager's wavefront error and then superresolved an image of Earth's moon. Sure enough, it snapped into focus.

THE NEXT GENERATION of space telescopes will make good use of the clarifying powers of our software. To fit inside a rocket, newer space telescopes will have mirrors that are segmented and deployed on orbit, where they will unfurl like the petals of a flower. By taking a few images and checking them, the modified Gerchberg-Saxton software can assess and correct the space telescope's wavefront error on orbit. We demonstrated the feasibility of this approach during the early stages of the James Webb Space Telescope project, which will be able to look much deeper into the universe than Hubble can. For the many contributions we've been able to make to the nation's space program, our group received NASA's Software of the Year Award in 2007.

We're far from finished with our work. Although we designed the software to sense wavefront error in light, the calculations are valid for any part of the electromagnetic spectrum. The Deep Space Network, a ground-based system of three 70-meter satellite dishes that JPL runs to communicate with NASA's spacecraft, suffers from the same basic problem of wavefront error. Our algorithm could be adapted to correct the network's aberrations.

But there's more. Our own eyes may one day also become beneficiaries of the software. Prescription eyeglasses correct for focus and perhaps astigmatism, but

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Research and education in subzero temperatures

Prof Tuomas Aura and Prof Antti Ylä-Jääski

A cold spell has taken over Finland and the snow covered university is beautiful during those few hours of the day when the sun peeks up. Indoors (nobody stays outdoors any more than necessary) work continues on creating the future Internet. Researchers and students continue debating what form should the infrastructure of the mobile revolution take. Should we rip the TCP/IP out of the Internet and replace it with a publish/subscribe paradigm? Should the routing information be encoded to the data packet and routers use Bloom filters to find the correct forwarding address, thus making the routers stateless and moving routing functionality to the end hosts? Or should we stick to IPv6 and solve everything with layers of middleware? Does a WebServices client in a mobile phone make any sense? The endless possibilities make discussions interesting and challenging.

A year ago we started our own research platform for mobile social media and the preliminary results from the OtaSizzle project are promising. The initial services, some created by our students, are competing with slightly more known offerings like the Facebook and the next generation is being planned. It seems that the best ideas come from those services that people create for themselves. Research results from the first year will be published soon, keeping our young the researchers busy writing their papers.

Meanwhile the traditionally closed telecommunications operators are starting to open their information systems to service developers. A new program called "Open Telco" is taking off. What would you do, if you could access an operator's database? Location is the first thing that comes to the mind, payment services the next. History of location could be scary, as the positioning of other customers. Having this access via relatively simple web-like interface called REST (Representational State Transfer) makes it almost too easy to combine cell phone user's location with other location based services. The new services we could create are exciting, but at the same time we are opening huge possibilities for misuse and creating privacy issues. Well, at least we are not creating an atomic bomb, but sometimes we think that we can understand what the nice folks at Los Alamos felt like, over half a century ago.

Our university has joined with two others to broaden our technological innovation base with economics and design schools. Having been TKK, Helsinki University of Technology, we are now Aalto University School of Science and Technology. But we continue to offer our two wonderful international Master's programmes within the topics of mobile software and security. The Erasmus Mundus Funded Master's programme in Security and Mobile Computing (NordSecMob) includes studies in two Nordic universities and our own Mobile Computing – Services and Security is held at our campus, which will be warm and green in just three or four months.

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those are just two ways that wavefronts can be distorted. In reality, there are many other subtle, higher-order effects that can degrade your vision. Correcting these effects will lead to what vision science researchers have termed superhuman vision, the enhancement of visual acuity beyond normal 20/20 vision.

Vision scientists already use techniques for wavefront sensing and control. Most modern LASIK procedures, for example, use Shack-Hartmann wavefront sensors to determine eye aberrations. But as we discussed earlier, the sensor's resolution is limited by the density of its lenslet array. The modified Gerchberg-Saxton algorithm, by contrast, is limited only by the resolution of the camera used to capture the points of light, which is in the realm of tens of millions of pixels. Some vision scientists have proposed the possibility of replacing their aberration-measuring equipment with our computations for the human eye.

We're also working on cutting down the amount of time the algorithm needs to complete the complex calculations. Our software performs a massive number of calculations, which can take a long time on a regular microprocessor. By translating these computations into a graphics-processing problem, we can offload much of the work from the CPU to run on high-performance graphics cards, in effect turning our desktop PCs into supercomputers. Now we can generate wavefront-error results in seconds, down from about 5 minutes. Evolving graphics technology will help the software come closer to running in real time.

Ultimately, our dream is to be able to correct astronomical images "on sky," with the software running in real time and using only camera imagery to continuously determine and correct wavefront error. On Earth, our goal is for crisp, unprecedented visual clarity. In all, we're helping to write a new legacy for Hubble, and we're turning a boondoggle into a boon for the entire electromagnetic spectrum. ❏

The authors would like to thank their collaborators, especially Scott Basinger, Joseph Green, Catherine Ohara, and Fang Shi.

USING HEAT TO DEFEAT BLUR

One unexpected way to fix blurry images involves heaters. Spacecraft instruments undergo large temperature swings, depending on their place in orbit and the angle of the sun. As a result, they tend to be kept under careful thermal control. Using our algorithm, we can figure out how to operate a nearby heater to change the optics to correct wavefront error.

Imagine, for example, that some component in an optical system changes its shape over time—a primary mirror warps under mechanical strain, causing light to bend in unintended ways and producing unfocused images. We could apply heat to expand the support structures, changing the distance between two mirrors in a space telescope.

We could also use heaters mounted to a particular mirror to bend it in a desirable way. We actually did this on the 1992 Mars Observer mission prior to its unfortunate demise; we are now building mirrors with heaters deliberately placed so that we can use them to control the wavefront. *—S.B. & D.R.*

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Imperial College London has been awarded almost £11 million over 5 years by the Wellcome Trust and EPSRC for a Medical Engineering Solutions in Osteoarthritis Centre of Excellence. There are a number of departments, divisions and institutes across Imperial College London participating in this Centre which will bring together a critical mass of Engineers, Clinicians and Basic Scientists, collaborating to use technology to improve the diagnosis, understanding, surgical management and rehabilitative treatment of Osteoarthritis. The Centre wishes to appoint 6 academic staff of which this post is one.

Applications are invited for the position of Chair, Readership, Senior Lectureship or Lectureship in Medical Device Engineering to start with effect from 1 August 2010, or as soon as possible thereafter. The level of the appointment will depend on the experience and track record of the successful candidate, and applicants are requested to indicate in their cover letter which appointment level they would expect to be appointed at.

The post is within the Institute of Biomedical Engineering, Faculty of Engineering at Imperial College London, based on the South Kensington Campus. The main interests of the Institute focus on Biomedical Engineering.

The positions in Medical Device Engineering will be responsible for directing a research programme aimed at better early detection and monitoring of Osteoarthritis to improve clinical intervention, and to monitor the efficacy and longevity of the intervention, be that conservative, surgical or pharmacological. This could be through the design of novel sensors or load cell arrangements for joint implants and the application of telemetered sensor systems for monitoring whole body and joint function, specifically the knee, during rehabilitation. In addition, the position would be responsible for the development of disposable "personalised" body worn sensors/systems for movement and gait analysis, again to assist treatment and rehabilitation, coupled with devices to measure vital signs and exercise routines in healthy patient cohorts prone to early onset Osteoarthritis (e.g. athletes). It is envisioned that ultimately this will lead to the creation of new products.

The appointee will be expected to conduct research of outstanding quality. Specifically, he or she will be expected to seek and obtain external research funding, attract and supervise high-quality PhD students, publish papers in prestigious refereed journals and present research findings at international conferences. The appointee will be expected to interact with Scientists, Engineers and Medics from across College in a multidisciplinary fashion.

The applicant will have a previous track record of applying sensor technology for disease monitoring in its broadest sense, and will also have experience in the commercial exploitation of intellectual property, resulting from the applicant's research programmes in the area of medical devices. The post will require experience of sensor development and the deployment into medical devices.

The appointee will contribute to the work of the Institute and Centre by:

- Planning and directing a research programme;
- Planning and leading innovative, interdisciplinary research;
- Successfully attracting funds for major research initiatives;
- Extending and interlinking the existing research strengths of Imperial College London in the field of medical device technology;
- Participating in postgraduate teaching and research supervision.

The post holder will plan and direct the implementation of research activities and programmes of outstanding quality, international repute and innovation in the field of medical device engineering and advance the reputation of the Centre, the Institute and the College.

Our preferred method of application is online via the Imperial College website at http://www3.imperial.ac.uk/employment where you will find the further particulars for this post. Please select "Job Search" then enter the job title or vacancy reference number **EN20100015** into "Keywords". Complete and upload an application form as directed.

Alternatively, you may e-mail your application and CV to: Maria Monteiro, e-mail: m.monteiro@imperial.ac.uk; Tel: +44 (0)20 7594 5498.

Please contact Dr Rob Fenton, Research & Development Director, to discuss this post informally at: r.fenton@imperial.ac.uk

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Faculty Positions in Mechatronic Systems Engineering

School of Engineering Science Simon Fraser University

The School of Engineering Science at Simon Fraser University is seeking outstanding candidates for tenure track positions at the rank of Assistant Professor for its newly developed program in Mechatronic Systems Engineering (MSE). As of Fall 2007, the School has been offering graduate as well as a Co-op based undergraduate degree programs in MSE at SFU's newest campus in Surrey. The areas of specific interest are:

1) Mechanical/Mechatronic Design with a broad background in design theories and methodologies and hands-on engineering design experience. Special consideration will be given to candidates with demonstrated practical skills in design of mechanical systems in areas such as smart mechanisms, product design, electromechanical system integration, and/or micro-mechatronics.

2) Materials Engineering with a strong background in both experimental and theoretical aspects of solid mechanics applied to the development of advanced materials, with particular emphasis on micro/nano materials, multi-scale materials, smart polymers and emerging energy and biomedical technologies. Hands-on experience with fabrication, processing and experimental/characterization techniques is desirable.

3) Power Electronics including smart grid, novel power converters and control strategies, smart transmission and distribution systems, sustainable energy systems, distributed power generation, electric and hybrid electric vehicles, energy harvesting, energy storage systems, motor and adjustable speed drives, embedded computing for power electronics, and micro-grids.

4) Biomechatronics including biomedical technologies, biosensors, bioinstrumentation, neural interfacing and implants, medical robotics, rehabilitation and human augmentation technologies, biomechanical energy conversion, micro/nanotechnologies for diagnostic and therapeutic applications.

5) Sustainable Energy including sustainable energy conversion and storage systems; solar, wind, wave/tidal, and small hydroelectric power systems; fuel cells and batteries; hydrogen technologies; thermoelectric technologies; thermohydraulics of power systems; alternative drive train technologies and green transportation; green and energy efficient buildings.

Individuals with an undergraduate and a doctoral degree, from a reputable university, in Mechanical/Electrical/Mechatronic Engineering or a closely related area with a demonstrated potential for scholarly and funded research in one of the aforementioned research areas, as well as a commitment to undergraduate/graduate teaching are encouraged to apply. **The applicants should identify in their cover letter which one of the above five mentioned areas they are applying to.** Preference may be given to candidates with relevant industrial experience. Registration or eligibility to register as a Professional Engineer in the Province of British Columbia is required.

The School of Engineering Science has a strong commitment to high quality research and offers an excellent research environment. Initial research support will be provided to the successful applicants for establishing their research program. The University has consistently been placed at or near the top of the Maclean Magazine's national ranking. SFU Surrey campus offers brand new state-of-the-art facilities in a central location with outstanding access to metropolitan Vancouver.

All qualified candidates are encouraged to apply; however Canadians and permanent residents will be given priority. The University is committed to employment equity and welcomes applications from all qualified women and men, including visible minorities, aboriginal people, and persons with disabilities. Applications will be accepted until the positions are filled. Positions are available immediately but are subject to final budgetary approval by the University. Further, under the authority of the University Act personal information that is required by the University for Academic Appointment Competitions will be collected. For further details see:

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UNIVERSITÄT PADERBORN
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The Institute of Electrical Engineering and Information Technology at the University of Paderborn invites applications for a

Full Professorship (W 3) in System and Circuit Technology

The position is to be associated to the Heinz Nixdorf Institute where internationally recognized research teams work together on interdisciplinary projects in computer science and engineering.
We are particularly interested in applicants with a strong background in several areas of physically-technologically oriented circuit development, for example in

- analog, digital, mixed-signal technology for large systems,
- synthesis of such circuits and systems,
- low-power-electronics,
- robust and fault-tolerant circuit technology.

The successful applicant will have an outstanding recognized record of research in the areas of interest and will have the qualities necessary for academic leadership to develop both individual and collaborative sponsored research programs. In addition, the applicant will be expected to teach undergraduate and graduate classes and to be involved in service to the university and profession.

Applicants must have completed a Ph.D. degree and demonstrated an outstanding research potential in a postdoc phase.

Women and minorities are encouraged to apply. The University of Paderborn is an Equal Opportunity employer.

Candidates should submit their applications (CV, list of publications, copies of degree certificates, short research plan) by **31 March, 2010** to the Head of the Institute of Electrical Engineering and Information Technology, Prof. Dr. Sybille Hellebrand, University of Paderborn, 33095 Paderborn, Germany. Please also send your application as a single PDF-file to sybille.hellebrand@uni-paderborn.de.

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Department of Electrical Engineering at National Sun Yat-sen University (NSYSU) invites applications from outstanding candidates for faculty positions (Assistant Professor, Associate Professor, or Full Professor). Applicants of all areas in electrical engineering are welcome. However, applicants with (1) Control and (2) Power and (3) Communication related specialties/applications are most preferable.

Applicants should have a Ph.D. degree in electrical engineering or other related fields. Responsibilities include effective teaching at the undergraduate and graduate levels, and establish a strong research program that involves supervision of graduate students and acquisition of research grants.

Applicants should send, before April 30, 2010, (a) a curriculum vitae and Ph.D diploma, (b) transcript (for fresh Ph.D. applicants), (c) three recommendation letters, (d) publication list, (e) reprints of selected papers, (f) a statement on teaching and research plans, and (g) other supporting material to the following address:

Faculty Search Committee
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National Sun Yat-sen University
Kaohsiung, 80424 Taiwan
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Phone: +886-7-5252000 ext. 4103 Fax: +886-7-5254199
URL: http://www.ee.nsysu.edu.tw

NSYSU has been named by Ministry of Education (MOE), Taiwan, R.O.C., as one of the top seven research-intensive universities in Taiwan since 2002. It is also one of the 12 universities at Taiwan that have just been awarded the total 5-year, 50-billion NTS special development fund from MOE. The EE department is consistently ranked among 5 of the best EE programs in the nation, and is the only university in Taiwan with full scholarship support program for International Master of Electric Power Engineering.

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- Electromagnetics (with preference to terahertz imaging, remote sensing, electromagnetic exploration, geophysics, magneto-photonics, fundamentals of electromagnetic interaction, microwave photonics, and/or radio-frequency/microwave engineering),
- Control theory and/or multidisciplinary dynamical system modeling (a mechanical engineering hire with possible joint appointment in electrical engineering), and
- Graphene & Carbon Nanotube Physics (a material sciences and engineering hire with possible joint appointment in electrical engineering).

An earned Ph.D. in Electrical Engineering, Computer Science, Applied Mathematics and Physics, Statistics, or a related field, evidence of the ability to pursue a program of research, and a strong commitment to graduate teaching are required. Faculty members enjoy secure research funding from KAUST and have opportunities for additional funding through several KAUST provided sources and through industry collaborations.

Applications submitted as a single PDF/word file should include a cover letter, a curriculum vita with a list of publications, statements of research and teaching interests, and the names and contact information of at least 3 references for an Assistant position and at least 6 references for an Associate or Full Professor position. Applications should be sent via electronic mail to (ee@kaust.edu.sa) by April 1, 2010 to receive full consideration. The review of applications will begin immediately; however, applications will be considered until all available positions have been filled.

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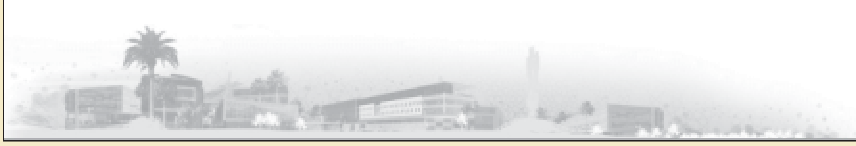

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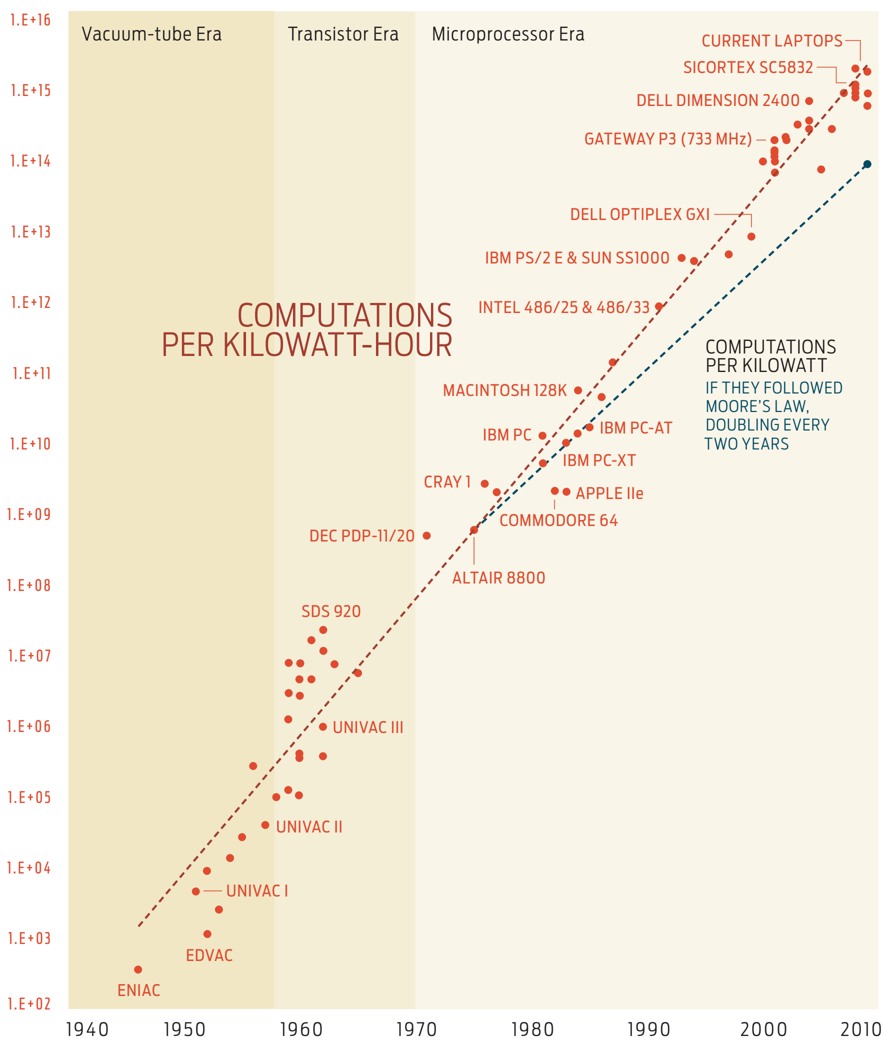

The complete study is available from the Intel Web site at http://download.intel.com/pressroom/pdf/computertrendsrelease.pdf.

Outperforming Moore's Law

THE NUMBER of transistors on a chip has doubled about every two years for decades, a trend that is popularly (but often imprecisely) encapsulated as Moore's Law. What is less well known is that the electrical efficiency in delivering computing performance began following a similar trend long before the microprocessor was invented.

The performance of desktop computers has doubled every 1.5 years, on average, since 1975, and in that time the number of computations per kilowatt-hour has grown about as quickly. But that measure of efficiency had also grown about that fast during the previous three decades, and even more rapidly during the vacuum-tube computing era and during the transition from tubes to transistors.

These are just a few of the conclusions drawn from a new study, "Assessing Trends in the Electrical Efficiency of Computation Over Time," prepared by me and my colleagues, researchers affiliated with Intel Corp., Lawrence Berkeley National Laboratory, Microsoft Corp., and Stanford University.

The main technology trends that have improved performance and reduced costs—at first better tubes, and then smaller transistors—also reduce power use, hence the similar improvements in computational performance and electrical efficiency, at similar rates, for such a long time. If these trends continue—and we have every reason to believe they will for at least the next 5 to 10 years—we can expect continued rapid reductions in the size and power requirements of computer-based devices. That should be especially welcome news for users of netbooks, smartphones, cameras, and other mobile devices.

—Jonathan G. Koomey

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