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The Last Days of CASH

HOW E-MONEY TECHNOLOGY IS PLUGGING US INTO THE DIGITAL ECONOMY

A SPECIAL REPORT ON THE FUTURE OF MONEY

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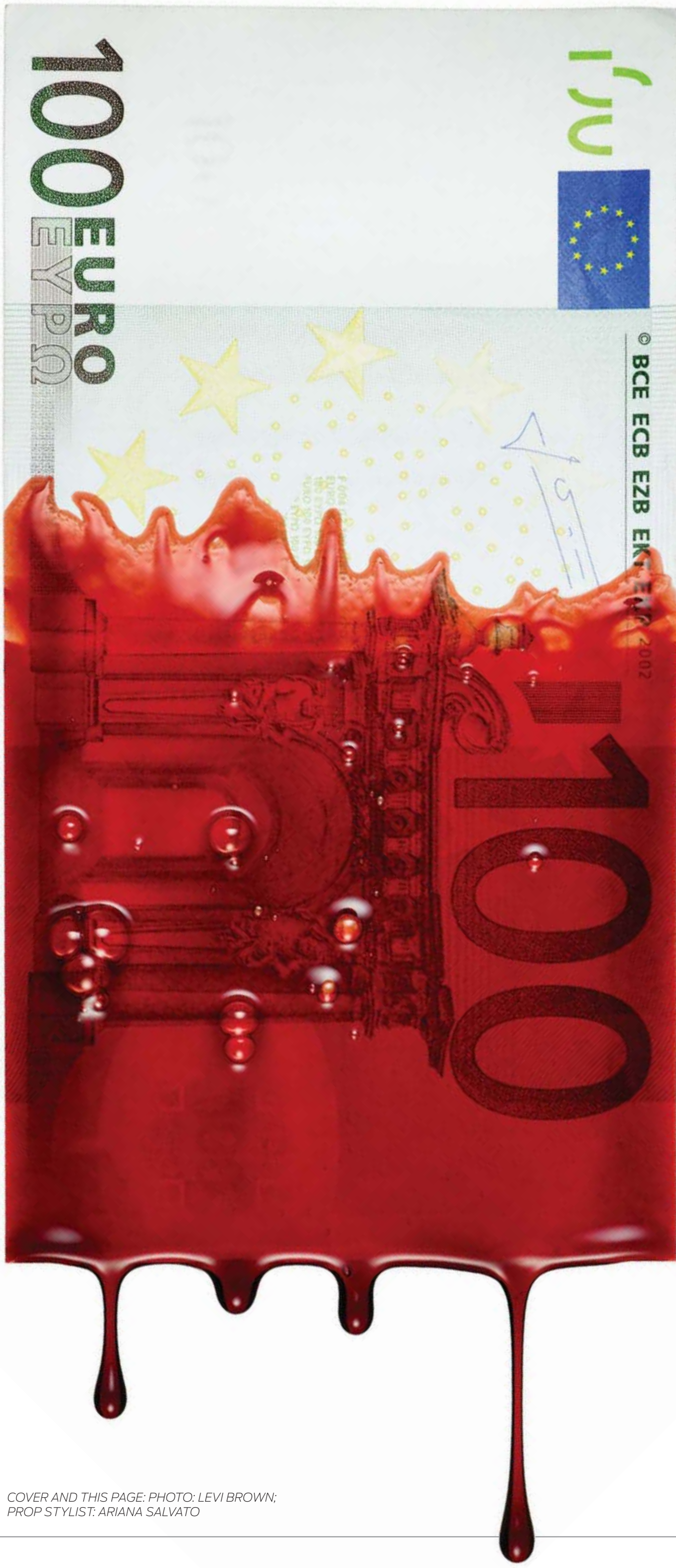

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Name
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Job Title
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Mechanical Engineering
Area of Expertise
Robotics
LabVIEW Helped Me
Bridge the gap between teaching theory and real-world design experience
Latest Project
Building a robotic tuna to swim across the Atlantic Ocean
NI LabVIEW
LabVIEW makes me better by making complex
CONTROL
simple and accessible

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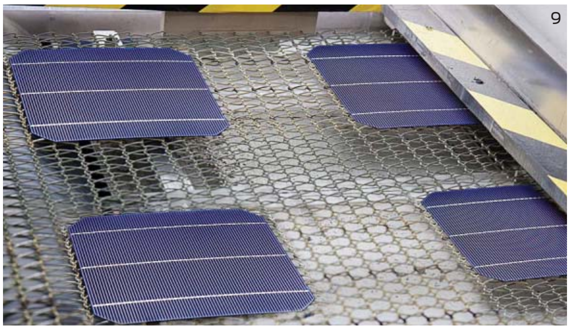

UPDATE

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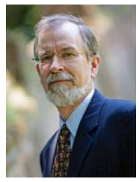
The Risk Factor Turns Five



Since 2007, Bob Charette has tracked hundreds of software and security failures, making his blog a must-read for IT pros eager to learn from the mistakes others have made.

ALSO
Video: Kickstarting Apple Toys

Kickstarter, originally designed for artists, is the new place for iPhone and iPad accessories like the Geode [left]. Capitalizing on Apple's cult of fans, start-ups are using the crowdfunding site to presell their products, with multimillion-dollar success.

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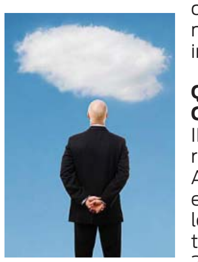
A VIEW INSIDE THE CLOUD
This month, *The Institute* takes a look at IEEE's work on cloud computing. Great for storing and accessing your documents, music, and photos from any device, cloud services are becoming increasingly popular. How can your company benefit, and what can you expect from these services in the future? To answer those questions and more, *The Institute* interviewed two IEEE experts in the field.



STANDARDS FOR SEAMLESS CLOUD COMPUTING
As more companies, government agencies, and consumers adopt cloud computing technologies, they're encountering turbulence along the way. To help clear the way, IEEE Standards Association working groups have been focusing for the past year on writing a cloud portability road map and producing an interoperability standard.

Q&A WITH THE 2013 CANDIDATES
IEEE members will be receiving their ballots in August for the annual election. To help them learn more about the two candidates for 2013 president-elect, *The Institute* interviewed Fellows J. Roberto Boisson de Marca and Tariq S. Durrani about where they stand on important issues.

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CLOCKWISE FROM LEFT: SUNIVA; JAMES KEGLEY; ICACHE; GARY S. CHAPMAN/GETTY IMAGES

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back story

The Mag-Stripe Era Ends

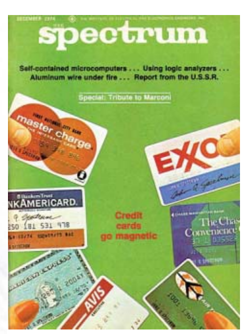
IN 1974, *IEEE Spectrum* published a cover story announcing the birth of the magnetic-stripe card, one of the most successful inventions ever. In this issue, some 38 years later, we've got an article that announces the impending death of the mag-stripe card.

Astoundingly, the same man, Jerome Svigals, has a byline in both articles. We're pretty sure this is the first time that the same person has announced, in the same magazine, the beginning and the end of such a momentous technology.

In the 1960s, Svigals was working as a systems manager for IBM in Asia. Those were the days when people often spent an entire career at one company and when IBMers joked that IBM stood for "I've been moved." So Svigals's experience in the late 1960s wasn't all that uncommon: His managers brought him back to the United States and then set about looking for a stateside job that fit his skills.

Svigals had worked with banking customers in the past, and IBM was kicking off a project that involved the banking industry. The gist of it was figuring out a way for customers to automatically and reliably identify themselves to machines. So they made Svigals development director for electronic banking, and his first assignment was to work with a senior scientist to consider possible technologies for that identification challenge. The two quickly settled on the magnetic stripe [see "The Long Life and Imminent Death of the Mag-Stripe Card"].

In 1974, IBM was ready to make some noise about the technology. Svigals, an avid *Spectrum* reader, urged IBM's PR people to contact us, and they did. We agreed to publish an article by Svigals and a coworker, Herman A. Ziegler. It was Svigals's first attempt to write something for a wide readership, and he still keeps a treasured copy of the issue in his files.



LEFT: JEROME SVIGALS; RIGHT: IEEE SPECTRUM

It was the start of something. He liked writing so much he went on to write a book on smart cards in 1985. Since then Svigals, now in his mid-80s, has published 27 books and about a hundred articles. "The positive forecasting in that article was absolutely on target," Svigals says today. "But we didn't expect mag-stripe cards to be used for things like hotel keys. We weren't *that* smart." ❑

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 Data is in *IEEE Spectrum*, Vol. 49, no. 6 (INT), June 2012, p. 80, or in *IEEE Spectrum*, Vol. 49, no. 6 (NA), June 2012, p. 88.

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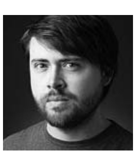
DAVID G.W. BIRCH, who wrote "Let a Thousand Currencies Bloom" [p. 26], is a director of Consult Hyperion, which specializes in secure electronic transactions. For 15 years he has organized the annual Digital Money Forum, in London, which explores the history and future of transactions. He first realized how little the public understood about money when a British journalist told him she'd always thought the pound was backed by a pile of gold in a basement. "I had to laugh," he says.

MICHAEL BROOKS, a British science journalist, holds a Ph.D. in quantum physics from the University of Sussex, which prepared him well to tackle the article "Quantum Cash and the End of Counterfeiting" [p. 56]. He says he found the topic of quantum money "absolutely fascinating," and adds, "I just hope I get to use some in my lifetime." He is the author, most recently, of *Free Radicals: The Secret Anarchy of Science* (Profile Books, 2011).



LEVI BROWN, the featured photographer for our special report, likes deconstructing materials to illustrate abstract concepts. For the Future of Money shoots, he attacked currency with blowtorches and acid, put coins in the oven, set fire to a 1000 yen bill, and made a €100 note bleed. This is his first assignment for *IEEE Spectrum*.

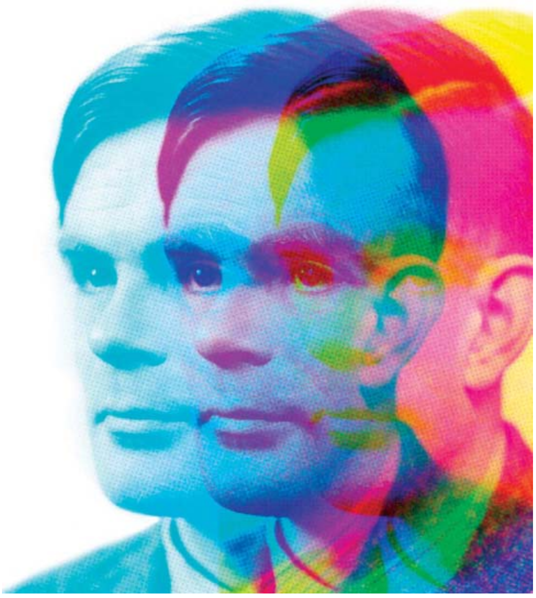
MORGEN E. PECK, who wrote "The Crypto-anarchists' Answer to Cash" [p. 48], never saw the point in writing about money or finance. Then she attended a conference on the cryptocurrency Bitcoin and talked to anarchists, programmers, bankers, cryptographers, libertarians, finance lawyers, and a game show host. From this crucible of ideas, she emerged quite altered. "I'd like to personally thank Satoshi Nakamoto [Bitcoin's supposed creator] for finally making money interesting enough to write about," she says.

JAMES SUROWIECKI writes *The New Yorker*'s popular business column "The Financial Page." He is also the author of the best seller *The Wisdom of Crowds* (Doubleday, 2004). In "A Brief History of Money" [p. 40], he traces the evolution of money and our shifting attitudes toward it. He found the task of condensing a few millennia's worth of material into one magazine article challenging, but also incredibly compelling. "Money is one of those things that's completely familiar and completely mysterious," he says, "and that makes it a great subject."

DAVID WOLMAN thrives on adventure. Once, in China, he talked his way onto a train running on the world's highest-elevation rail line, the Qinghai-Tibet Railway—before it officially opened. In "Cashing Out" [p. 38], he recounts another adventure: his attempt to give up cash for a year in preparation for writing his book *The End of Money* (Da Capo Press, 2012). Wolman is a contributing editor at *Wired* and writes for *The New York Times* and other publications.

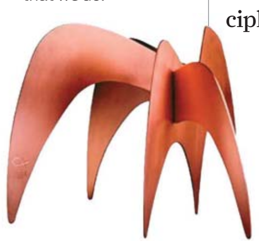
CLOCKWISE FROM TOP LEFT: CONSULT HYPERION; DAVID SUROWIECKI; BRETT PATTERSON; CHRISTOPHER GUDAS; LEVI BROWN; ANDREW PERRIS

spectral lines



IEEE SPECTRUM WINS GENERAL EXCELLENCE AWARD

In the United States, no journalism awards are more prestigious than the National Magazine Awards. In this year's ceremony, held in May in New York City, *IEEE Spectrum* was honored with the award for General Excellence in the "Thought Leader" category. *Spectrum* would like to thank the leadership and membership of the IEEE, whose support for and appreciation of rigorous journalism make possible all that we do.



Turing and the Test of Time

The centenary of Alan Turing's birth is being greeted by an extraordinary response, not only in mathematical and scientific circles but in a much wider public arena. It marks the awareness that he was one of the 20th century's seminal figures, whose brief life is better appreciated in the 21st century than in his own.

One reason for this fascination is that he was an unworldly person at the heart of an amazingly worldly achievement: the breaking of Nazi Germany's most closely guarded military ciphers. Entirely unknown to the public in his own time, his tour de force emerged only in the 1970s. (Even in 2012, his wartime papers are still being declassified, and the full story remains unwritten.)

Yet this triumph of reason is eclipsed by the fundamental discovery Turing made in 1936. At 24, he proved something very strange: There are tasks that can be described but cannot be carried out by a definite procedure, method, or process. This was his negative conclusion, but in order to establish it, he had to do something very constructive. He had to define what was meant by a definite procedure, method, or process. No one had ever done that, and Turing's solution came from the future.

His "Turing machine," then a new mathematical construct, is now easily seen as the abstract form of a computer program. In 1936, computers did not exist. But Turing defined the concept of the "universal machine," with the power to run any program. In so doing he invented the concept of the computer.

Turing's most radical idea resided within that invention. It was essential to his argument that instructions could be seen as a form of data. In modern computing, that is a commonplace: Programs act on programs. But in the 1930s, it was a strange and radical step, flowing from the abstruse and abstract logic of Turing's mathematical proof.

In 1945, fully aware of the power of electronic technology being used in wartime code breaking, Turing set out to turn his idea of a universal machine into an electronic digital computer. More important than the details of his hardware engineering design is the prospectus he launched for computer software, capable of encompassing "every known process" and embodying the modern logic of programs working on other programs.

Turing called his project "building a brain," and indeed, even from 1936, Turing's interests centered on modeling the human mind. His later 1940s work developed ideas for artificial intelligence, and in 1950 he went on to found a completely new field in mathematical biology, using computer simulation to study growth and form in plants and animals. But his fascination with the brain reemerged in his famous paper of 1950, "Computing Machinery and Intelligence," which explains the so-called Turing Test for machine-based intelligence.

The paper has attracted a wide readership, not just for its bold argument but for its wit and humor. Turing's subtext was a vigorous statement that he was entirely human.

The success of this publication was at odds with his own reticence to claim the origin of the computer as his own. He did little to attach his name to it and in his own lifetime was written out of the story.

Even so, the revelations of his wartime triumph have rescued the remarkable accomplishments of an unusual genius who combined the highly abstract with the hands-on approach of an engineer. His modern-minded openness as a gay man, one who suffered prosecution and punishment in 1952, has also attracted great attention. Alan Turing is a hero of the theory and practice of computer science. Adding his roles in the human dramas of war and sexuality, he has achieved a special place in history.

—Andrew Hodges

Andrew Hodges is a fellow in mathematics at the University of Oxford and the author of the 1983 biography Alan Turing: The Enigma, *which was reissued this year by Princeton University Press.*

TOP: ORIGINAL PHOTO, PICTORIAL PRESS/ALAMY; BOTTOM: RANDI SILBERMAN KLETT

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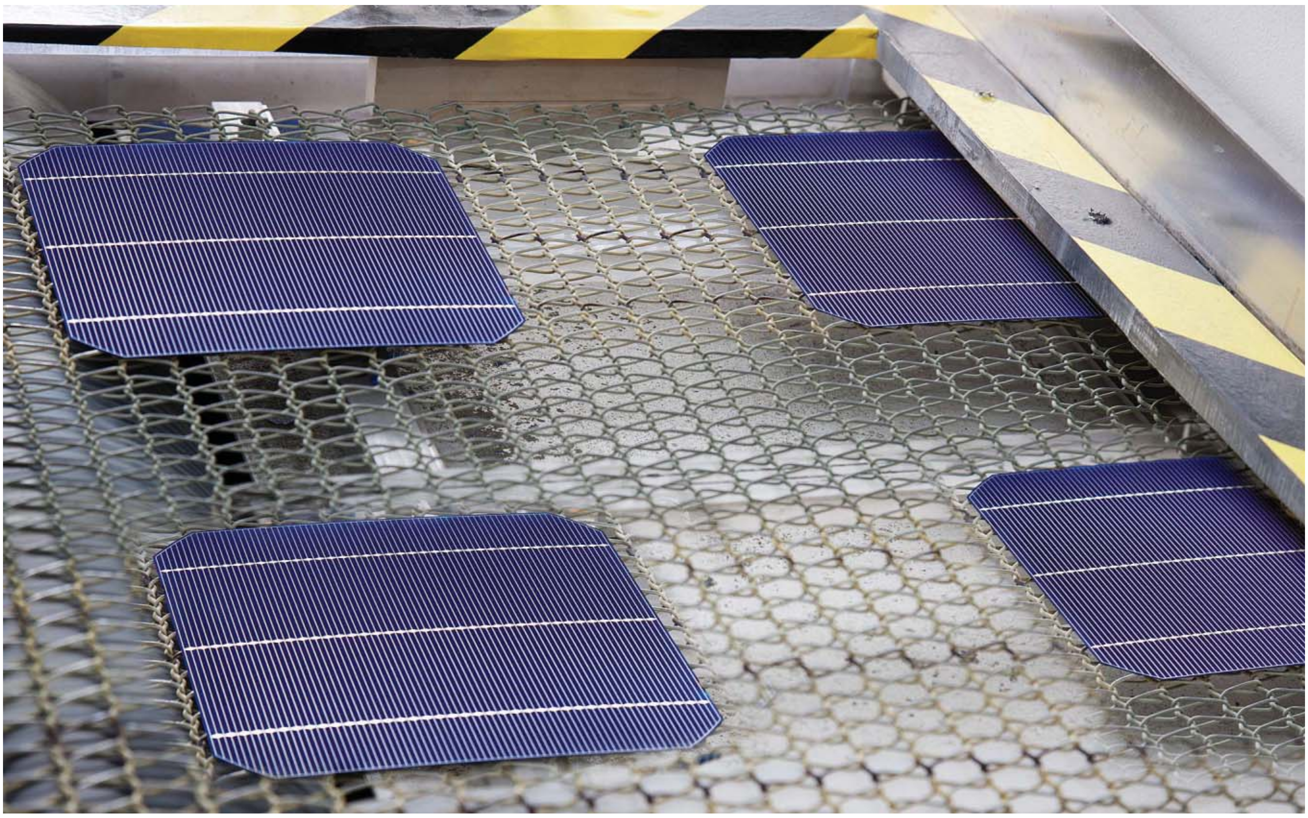

The Solar Efficiency Gap

Companies continue to push solar-cell efficiency records toward theoretical limits. Are actual production-line solar panels keeping up?

IN LATE MARCH, solar-panel manufacturer SunPower Corp. announced that it was beginning limited production of its record-breaking crystalline silicon solar cell, which can achieve up to 24 percent conversion of the sun's energy.

That record efficiency is just for individual solar cells, though, and the full panels SunPower makes will likely not get close to that mark: Typically, for these technologies, efficiencies rarely range above 16 to 18 percent. When you consider that the record efficiency for such a cell is over 27 percent and that the theoretical limit is around 29 percent, 16 to 18 percent doesn't seem so great.

There are a number of reasons that solar-panel efficiencies are unable to approach those of the record-setting, or champion, cells, and they're also the reasons that solar isn't yet quite up to par, economically, with other energy sources. But the gap seems to be closing.

"Over time, the difference between the champion cells and what's coming off the commercial production lines has been shrinking," says Sarah Kurtz, a scientist with the National Renewable Energy Laboratory (NREL), the section of the U.S. Department of Energy that officially confirms solar-cell efficiency records. She cites some NREL data on monocrystalline silicon panel efficiencies from a sampling of companies: The average rose from 12.4 percent in April 2004 through 14.2 percent in April 2008, all the way to 15.4 percent last November. Over that same period, the record for such a cell has basically stood still.

TOP OF THE LINE: The efficiency of solar modules lags that of the record-setting cells that companies produce. But "flagship lines" like those incorporating Suniva's ARTisun Select cells offer better performance—for a price. *PHOTO: SUNIVA*

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update


GETTY IMAGES

news brief

EGG-FET
Always on the lookout for a new material to give flexible electronics an edge, engineers at the National Cheng Kung University, in Tainan, Taiwan, found one in the kitchen refrigerator. Egg whites, it turns out, make an excellent gate dielectric, the thin layer of insulation that's key to controlling an organic field-effect transistor, or OFET. The researchers constructed several OFETs using organic semiconductors, egg whites, and metal contacts and got good results on both flexible and rigid substrates.

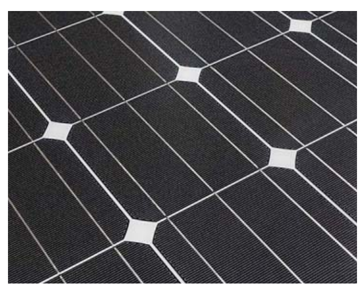
The main reason that panel efficiencies can't reach all the way to those of the cell records is size. A champion cell is just that—a cell: an individual, small bit of photovoltaic material that can use basically all of its area to convert sunlight into electricity. But you can't power a home on an individual cell, you need a module: full panels with multiple cells that can actually be hooked to an electrical system. As soon as you try to combine a bunch of those cells into a module, there are significant losses.

"With a module, there are parts in between the cells—there's the aluminum frame, things like that. And when you're looking at a module, you're taking into account that entire area," says M.J. Shiao, a senior analyst with GTM Research, a market analysis firm based in Boston that focuses on green technology. In other words, not all of a solar panel is actually used to convert light to electricity.

Most crystalline silicon production lines average somewhere around 15 percent efficiency for full modules. Shiao says that manufacturers already have the technology to bump that toward 20 percent. One possibility is to use a textured solar cell to help trap light by reducing reflection; another is to use a rear-contact architecture, which basically allows cells to connect to their neighbors in a way that doesn't cast a shadow on them. But for now, these techniques can't be used at a cost that would make sense.

When they're aiming for a record, companies use manufacturing processes that are entirely different from those they use on an assembly line. "A champion solar cell, in general, needs to be essentially defect free," says NREL's Kurtz. "To get the highest efficiency, the materials need to be perfect." Record cells typically need many extra processing steps: extra refinement of materials, smoothing out of imperfections, and so on. But in manufacturing, more steps mean more money; keeping the process simple is critical to holding down costs.

Bruce McPherson, vice president of R&D at photovoltaics firm Suniva, says one key to bringing the company's cell production average up above 19 percent has been keeping extra steps out of the process, like using lasers to cut a groove into the edges of cells. "And frankly, we believe that there are further upsides that we see very clearly in the lab and are now working to get into manufacturing," he says.


SUPER SOLAR: Yingli Solar's Panda module includes some of the company's top-performing cells. *PHOTO: YINGLI*

The difference between champion solar cells and their production line counterparts is still significant, though, and small improvements in individual steps or cutting out one or two along the line won't jump a cell by 4 or 5 percent up toward a record. "Manufacturers are definitely all about getting a 0.1 percent efficiency gain using the same equipment," Shiao says.

Some companies, though, have started to use the difference between record-setting cells and standard cells as a marketing tool. Suntech, Trina, Yingli Solar, and others now have what they're calling "flagship lines" with names like Pluto, Panda, and Honey, that incorporate record-holding cells into more expensive modules.

But for mainstream modules, manufacturers will have to be satisfied with scraping away a tenth of a percent or so with each incremental improvement. That is, until something drastic changes—a new version of a process or a big enough drop in a material's price to allow an extra processing step to be added.

The latter scenario may be going on right now. The price of a kilogram of polysilicon—the primary feedstock for crystalline silicon cells—dropped below US $30 in April from $80 in early 2011. This has contributed to a drop in the price of solar PV modules to below $1 per watt at the end of 2011, meaning there could be more room for adding those efficiency-improving steps to production.

Still, Kurtz says that major efficiency upgrades are becoming less likely, given the current overall solar market. "I think the efficiencies are going to continue to creep up, but the rate at which they creep up is primarily dependent upon the availability of the development funds, the R&D-type funding to make those changes," she says. And such funding isn't pouring in right now.

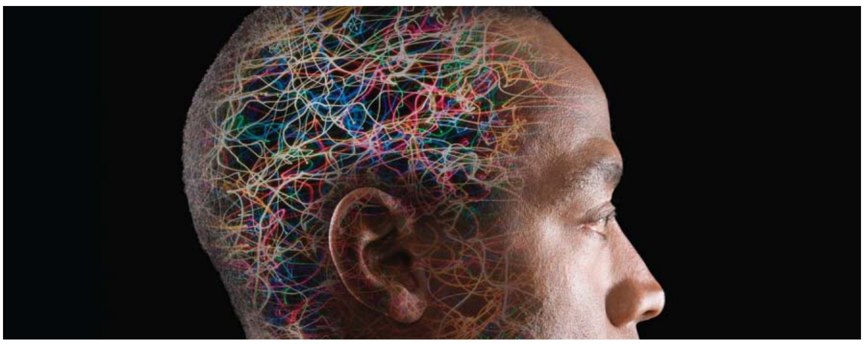
"But the difference between the record-efficiency cells and the module efficiencies is shrinking; that's the big picture," Kurtz adds. "And that's going to continue to happen for a few years."

—Dave Levitan

2 Number of nodes in the first "universal" quantum information network. The network can handle the ephemeral and easily lost quantum states of photons needed for hack-proof communications.

Electromagnetic Depression Treatment Nears Approval

Deep transcranial magnetic stimulation adds to psychiatry's arsenal of electronic remedies



JOHN LUND/GETTY IMAGES

A new type of brain stimulation device for combating difficult-to-treat cases of major depressive disorder is likely to break into the large American market soon. Its maker, Jerusalem-based Brainsway, plans to apply to the U.S. Food and Drug Administration for permission to market the device this month. The move follows initial results from a large-scale trial of the system, in which 30.4 percent of treated patients went into remission and 36.7 percent showed significant improvement. Research into device-based treatments for psychiatric problems has grown rapidly, and if the FDA gives its go-ahead, Brainsway's system will become the fourth device-based therapy to go on the market since 2005.

Deep transcranial magnetic stimulation (TMS), as its name suggests, uses magnetic fields to stimulate activity in structures deep in the brain. The patient wears a helmet in which powerful, specially designed electromagnets have been carefully positioned. When a pulse of electricity flows through the magnets' coils, the resulting magnetic field induces current to flow through a portion of the brain.

There are subtle differences between deep TMS and repetitive transcranial magnetic stimulation (rTMS), a brain stimulation tool widely used in research and also marketed as a treatment for depression. The electromagnetic elements in deep TMS are designed to produce a magnetic field that reaches its greatest strength deep within the brain. Ordinarily, magnetic fields fall away quickly inside the brain, but the orientation and structure of the coils in deep TMS lessens that effect. "The concept was to reduce the rate of reduction of the magnetic field as a function of distance," says Abraham Zangen, coinventor of the technology. In contrast, rTMS typically uses a single coil that produces a tightly focused field just a few centimeters below the brain's surface.

"The Brainsway coil is more like a shotgun than a rifle," says Mark S. George, a pioneer of TMS and director of the brain stimulation laboratory at the Medical University of South Carolina, in Charleston. It's unclear which weapon will be better at fighting depression. A tightly focused stimulation might be best if researchers knew exactly where to target that stimulation, he says, but they don't.

The 30.4 percent remission rate Brainsway is claiming may not seem like much, especially when 14.5 percent of patients who underwent a sham procedure also recovered, but in the context of antidepressants it is quite good, according to experts. The patients enrolled in the trial had already been failed by at least one drug treatment, and studies have shown that the odds of success with subsequent drugs decrease. What's more, as a group the treated patients on average showed a three-point improvement on the Hamilton depression rating scale, which doctors use to evaluate the severity of depression. "If you compared the three points to some antidepressant studies, it's above average—quite a lot above average," says Uzi Sofer, Brainsway's CEO. "Some medications are approved and marketed with a 1.5- or 2-point difference in the Hamilton."

Brainsway executives expect their device to have an easier time with regulators than previous devices did, particularly Neuronetics' rTMS system, NeuroStar. Although it was ultimately approved, NeuroStar's initial results were a bit ambiguous, and as the first of its kind, the device suffered from a procedural problem that meant it had to be compared to electroconvulsive therapy. ECT is an inconvenient treatment and can have side effects that scare many patients, but it's amazingly effective and was a high bar for Neuronetics to hurdle. However, with NeuroStar already on the market, the FDA lowered the bar for Brainsway, and the company is expected to surmount it.

"If these data hold up under peer review, if they are as they seem, then they are unambiguous," says George.

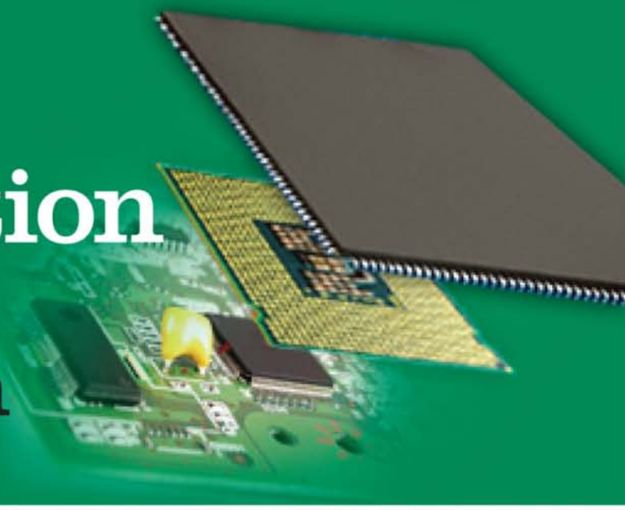
—Samuel K. Moore

ELECTRONICS

Special Advertising Section

Chip-Package-System Simulation

The Complete Electronics Solution



Chip–package–simulation is making it easier to design products faster, more efficiently and at lower cost.

There is growing pressure to produce new and compelling electronics products with better performance and at lower cost. This has raised both consumer and business community expectations; it has also disrupted historic industry product development cycles and market planning patterns.

Nowhere is that more evident than in engineering simulation, which is revolutionizing the product development process.

New simulation-driven chip–package–system (CPS) methodologies make it possible to provide the entire electronics supply chain with a more robust and reliable design that has greater predictability.

With more than 40 years of success under its belt, ANSYS recently augmented its reputation as a global innovator in simulation software and technologies for optimizing product development processes with the acquisition of Apache Design, a leading provider of simulation software for the electronics industry.

Since ANSYS acquired Apache Design in 2011, the two companies have been developing integration programs that leverage and build on the cultural similarities of each team. One of the results of this effort is a chip–package–system design approach that provides engineers with enough knowledge and confidence to make optimal cost, performance and reliability decisions for their designs.

ANSYS has built a reputation in software solutions with a strong and well thought-out systems vision in product development and design; Apache Design's electronic package, integrated circuit and printed circuit board tools enable engineers to design power-efficient devices while meeting growing performance demands for specific industry sectors, ranging from consumer electronics to automotive, turbomachinery, marine, aerospace, energy and a variety of other fields.

Historically, ANSYS has provided comprehensive solutions for signal integrity design and engineering, electromagnetic interference (EMI), and other aspects of simulation. "The missing piece was the integrated circuit," said Larry Williams, director of product management at ANSYS. Now, Williams said, ANSYS has access to the full spectrum of systems-level engineering solutions.

"In electronics design, there are packages, boards, systems and integrated circuits. We see great opportunity for engineering teams to expand on what electrical engineers can examine — what we like to think of as an ecosystems approach."

SMART EVERYTHING

"There is an engineering renaissance under way enabled by the presence of electronics in all the devices we use and interact with: namely smartphones, smart cards, smart sensors, smart meters, smart cars, smart TV. And many other devices that we use are tagged 'smart,'" said Aveek Sarkar, vice president of product engineering and support at Apache Design. "To meet these applications, electronics systems are evolving at a rapid pace, with chip or integrated circuit designs becoming increasingly complex, even for seemingly mundane requirements." For system manufacturers and IC suppliers, the challenge involves meeting rapidly evolving market needs while managing margins and design specifications of power and performance.

"Adding Apache Design technology

There is an engineering renaissance under way enabled by the presence of electronics in all the devices we use and interact with: namely, smart products.

to the mix expands the breadth, depth, functionality, usability and interoperability of ANSYS simulation capabilities," said Sarkar. It opens the door to more comprehensive systems simulation, enabling engineers to predict product behavior long before reaching the integration stage.

Increasingly, best-in-class design teams are adopting a simulation-based approach. "Given the performance, size and cost constraints, packages and boards used in today's mobile systems can no longer be off-the-shelf or based on design re-use," said Sarkar. "They must be designed together."

Sarkar noted that the multiphysics (ability to simulate various physical phenomena across chip, package and system) and multiscale (simulation technologies that span from nanometer scale in chip design to meter scale) codesign approach helps integrated circuit designers to model the impact of the package and printed circuit board on the performance and reliability of their designs. "This approach helps all electronics system designers, including handset and automotive designers, to verify their board's power deliver network and signal routing along with other component specifications," he said. This not only accelerates the design cycle and prevents multiple design iterations, it helps in reducing overall system cost by optimizing the system in an integrated manner. It also promotes a collaborative design environment across engineering teams.

Equally important for product vendors, the CPS simulation process significantly improves customers' productivity and integration, reduces time to market, and expands design trade-offs, potentially improving margins and the competitive environment.

HIGH EXPECTATIONS

With growing sales of smartphones (more than 2 billion people worldwide will own at least one smartphone in 2015, according to a Parks Associates forecast) and tablet computers (Gartner projects media tablet sales will reach 119 million in 2012, a 98 percent increase over 2011), engineers are continually working to add more power efficiency and functionality to their next-generation mobile product designs.

"One year ago, tablets were a new and unproven market, and now they — along with

other mobile-connected devices, including smartphones and e-readers — are leading the entire industry to positive growth," said Steve Koenig, the Consumer Electronic Association's director of industry analysis.

"Consumer desire has accelerated the traditional phone replacement cycle and will drive near-term hypergrowth of the smartphone market," added Harry Wang, director of mobile research at Park Associates, a global market research and consulting services firm.

Simulation is also playing a larger role in the automotive sector, for which high-performance computing is crucial to the design/development process. ANSYS worked with the acclaimed Red Bull Racing team to test and make quick design changes to its Formula 1 championship cars. The same technology made it possible for ANSYS software to help Toyota design its Prius hybrid vehicle.

The ability to virtually study how components and processes behave under different conditions — without first committing to a final design — has been instrumental in the growth of automotive onboard electronics. The current growth estimate is 30 percent; the forecast is 40 percent of the total cost of vehicles in the next few years, providing automobile manufacturers with a unique opportunity to differentiate their products.

THE BOTTOM LINE

"We're very optimistic about this new simulation flow that enables engineers to resolve many of their toughest design challenges," said Williams. "The CPS solution provides fully coupled chip-aware, physics-aware simulations for the chip-package-system design. The best-in-class dynamic power extraction solution from Apache Design is now coupled to industry-standard physical extraction simulators from ANSYS, providing full electromagnetic extraction, signal and power integrity and electromagnetic interference analysis, and thermal, mechanical stress and other solutions needed as 3-D integrated circuit technologies become mainstream."

ANSYS is now developing next-generation capabilities and products. With growing demand for wireless broadband (wireless data traffic in the U.S. jumped 123 percent in 2011 over 2010),

Best-in-class dynamic power extraction from Apache is now coupled to physical extraction simulators from ANSYS, providing full electromagnetic extraction

simulation is bringing more focus on signal integrity design, including the development of hybrid solutions — combining, for example, circuit simulation with other critical parts of a design. "This is a philosophy that ANSYS shares with customers," said Williams, "along with contibuting advancements in high-performance computing and other areas."

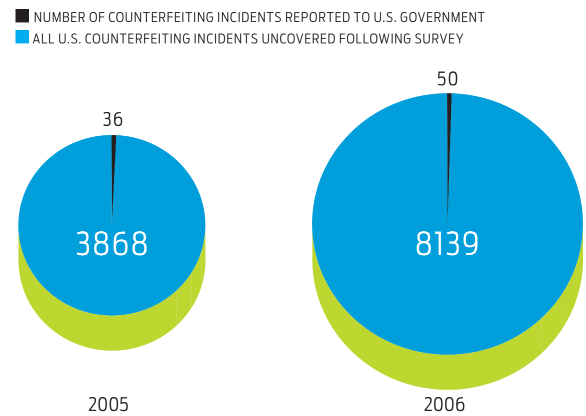
update

Counterfeit Chips on the Rise

As more firms report finding phony chips, the danger they pose becomes clearer

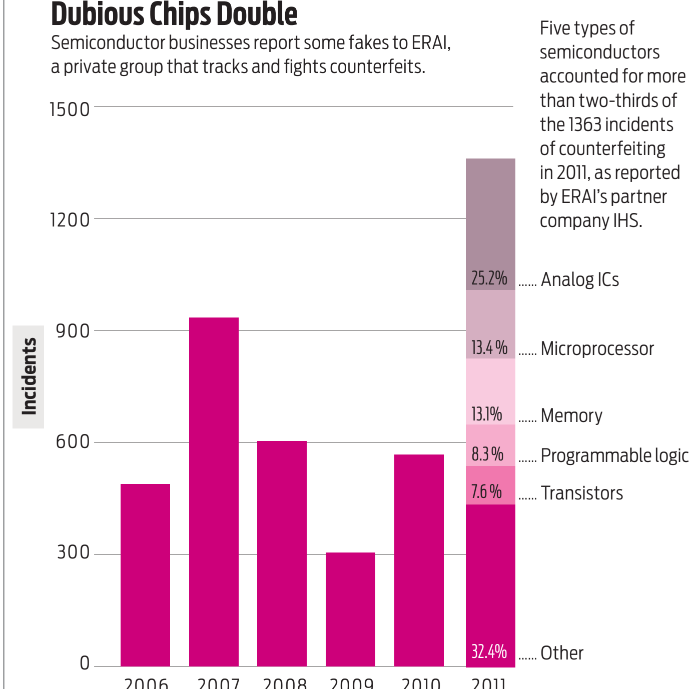
A Bigger Problem Than It Seemed

Companies don't usually report counterfeit chips to the U.S. government when they find them. A mandatory survey conducted by the U.S. Commerce Department in 2009 showed that less than 3 percent of incidents were reported in 2008.



Dubious Chips Double

Semiconductor businesses report some fakes to ERAI, a private group that tracks and fights counterfeits.



Making semiconductors is a big business—and, so it seems, is counterfeiting them. Just how big is becoming clearer than ever, thanks in part to the candor of the U.S. military, and it will become even clearer as new laws in the United States come into effect later this year.

In 2011, over 1300 counterfeit incidents were reported from around the world to Electronic Resellers Association International (ERAI), a private company that tracks counterfeit electronics for the industry. That's more than double the number reported in 2010 and 2008, and quadruple the number reported in 2009. ERAI's partner company, IHS, reported a slightly higher figure for 2011 by including data from the Government-Industry Data Exchange Program, a not-for-profit organization that, among other things, tracks counterfeits and component failures in the United States and Canada.

The fear is that these counterfeits—including used and relabeled commercial gear or components falsely labeled as military grade—will fail more quickly than the parts they're standing in for. And because semiconductors are an integral part of everything from cellphones to nuclear reactor controls, the failure of a counterfeit chip in the wrong place could have deadly consequences.

"That's what we're all afraid of, " says Jack Stradley, an expert on the U.S. government's semiconductor supply chain.

The new legislation, the National Defense Authorization Act for Fiscal Year 2012, aims to fight counterfeiting by requiring government contractors to track and report counterfeits and to be held accountable for replacement costs.

Until now, companies rarely reported fraudulent chips, says Lawrence Hurst, product fraud prevention manager at Intel. "We haven't been doing that," Hurst says. "In fact, most of the industry hasn't." In the past there was simply no financial reason to do so, he says. But with a new legal responsibility, Intel is now in the process of creating a database of counterfeit parts it encounters.

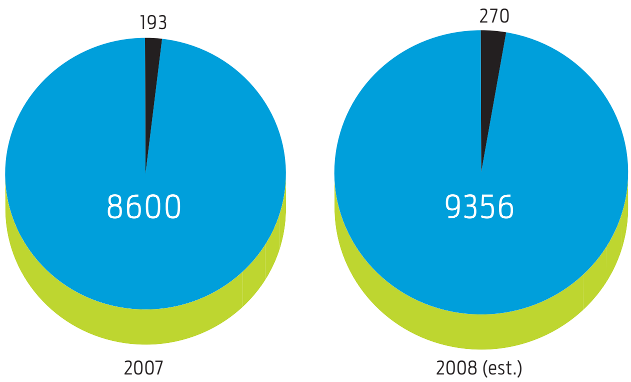
The U.S. law is in response to a 2010 U.S. Government Accountability Office report on counterfeits in the military and a 2011 congressional hearing on the dangers of counterfeit electronics. A report introduced in the hearing, based on a mandatory survey of producers, dealers, and military contractors, estimates that 9356 fake parts were found in 2008 alone.

Those same counterfeits are sold internationally. Both the Japanese Ministry of Defense and the U.S. Navy bought electromagnetic interference filters from Raytheon, later found to contain counterfeit versions of Fairchild semiconductors. The United Kingdom subsidiary of military contractor General Dynamics also bought counterfeit semiconductors, though it discovered the fraud before including the components in its products, according to the 2010–2011 annual report by the U.K.'s IP Crime Group.

The few prosecuted cases of counterfeit goods distribution show that it's easy to sneak products into the

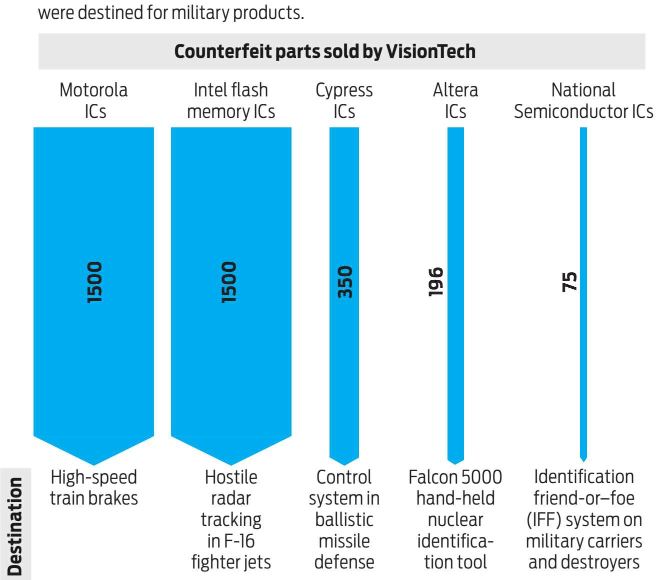
The survey revealed that counterfeit chips were found in the U.S. Navy's **Seahawk helicopters**, Boeing **Poseidon jets**, and U.S. Air Force **C-27J transport planes**.

Source: *Defense Industrial Base Assessment: Counterfeit Electronics*, January 2010, U.S. Department of Commerce



A Case Study in Fake Chips

In 2010 the United States prosecuted its first case against a counterfeit-chip broker. The company, VisionTech, sold thousands of fake chips, many of which were destined for military products.



Source: Sentencing memo, *United States of America v. Stephanie A. McCloskey*, filed 7 September 2011

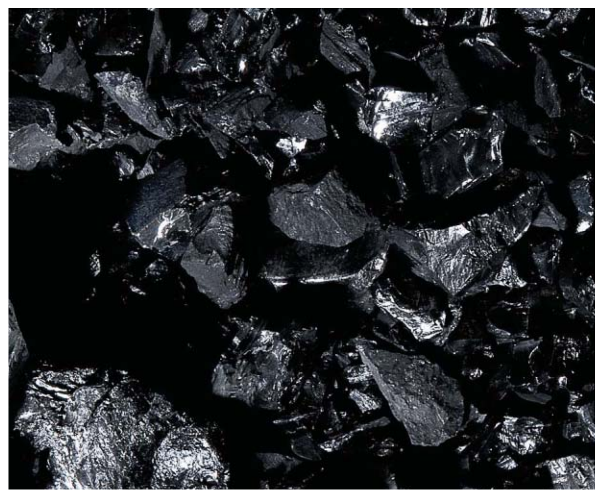
increasingly complicated supply chain. Between its point of manufacture and its use in an action-ready missile, a semiconductor is often bought and resold many times. Overworked purchasers rely on brokers, who in turn buy from relatively anonymous online forums. In theory, chips are tested at multiple points in the supply chain, but shady companies have lied about tests, authenticity, and origins. The majority of counterfeit chips can be traced to China, but the primary fault lies in the industry's purchasing practices, Stradley says.

Stradley believes that the new law won't do enough to force reform of the semiconductor supply chain. It may take a fatal disaster to do that. "It's always that way," says Stradley. "That's part of the problem—we haven't had any serious accidents we can point to."

—Celia Gorman

Cleaner Coal's Last Stand

China's first coal-gasification power plant starts operating amid high hopes, delays, and cost overruns



ELIZABETH WAUGH/GETTY IMAGES

For more than three decades, gasification technology has promised a smarter conversion of coal to electricity. By using heat and pressure to turn coal's motley mix of molecules into a consistent stream of simple gases, gasification plants squeeze more power from a ton of coal and control the resulting by-products better. In April, engineers in Tianjin, China, fired up a gasification power plant that will provide a "critically important" test of the technology's commercial potential as a low-carbon power source, according to Julio Friedmann, who leads the carbon management program at Lawrence Livermore National Laboratory, in California.

At 250 megawatts, the facility, known as GreenGen, is the world's largest integrated gasification combined cycle (IGCC) generator. It's also the first built explicitly as a test bed for capturing carbon. This combination of carbon capture and commercial scale is needed to evaluate coal gasification's potential contribution to stopping and reversing human-accelerated climate change. "We still have no plan as nations or as a world to make really deep greenhouse-gas emissions cuts. We have not economically vetted most of our important options, including IGCC plants such as GreenGen," says Friedmann.

GreenGen more closely resembles a refinery than a generating station. IGCC plants turn coal into a blend of gases before burning those gases to drive both gas

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920 KILOMETERS Distance over which optical atomic clocks, the most accurate variety, can now be synced with each other.

update

news brief

JAMES WEBB'S INFRARED EYE

Following 10 years of work by more than 200 engineers and scientists in Europe, the first instrument for the James Webb Space Telescope was handed over to NASA in May. The James Webb is the successor to the Hubble Space Telescope. The Mid-Infrared Instrument is sensitive enough to see a candle on one of Jupiter's moons. Scientists will use it to peer into the clouds of dust and gas where stars and planets form.

MPIA

and steam turbines. Unlike all IGCC plants that preceded it, GreenGen is designed to support an additional process whereby its carbon waste is extracted before combustion. Gases from the gasifier react with steam to produce hydrogen to fire the plant's turbines and a pure stream of carbon dioxide that is far easier to capture than the diffuse CO_2 in a conventional power plant's flue gases.

GreenGen and the handful of other IGCC coal plants in various stages of construction worldwide—including another plant in China and two in the United States—are the sole survivors among dozens of IGCC projects proposed and shelved over the past decade. Most fell by the wayside only in the past few years. A push for carbon legislation in the United States collapsed, as did the 2009 climate treaty negotiations held in Copenhagen. Without such measures, utilities have no incentive to invest in carbon capture. Over the same period, coal progressively lost its status as the cheapest fuel for power generation, as hydraulic fracturing operations flooded the natural gas market and slashed gas prices.

The resulting IGCC casualties include even FutureGen, the flagship project in the U.S. Department of Energy's Clean Coal program and the inspiration for GreenGen. The Bush administration killed FutureGen in 2008 amid rising costs. The project may return under President Obama but as a test of a simpler but even less-proven low-carbon coal scheme known as oxyfuel combustion [see "Restoring Coal's Sheen," *IEEE Spectrum*, January 2008].

Survivors such as China's GreenGen could renew IGCC's

NEXT UP: Duke Energy's IGCC plant should start up this year in Indiana, but the technology's future is probably in China. *PHOTO: DOUG McSCHOOLER/GETTY IMAGES*

appeal if they prove the technology's commercial promise. But critics say that delays and cost overruns in these projects may well undermine that. GreenGen started more than a year later than projected. And even proponents say it could take the remainder of this year for Huaneng Group, the state-owned utility behind GreenGen, to work out its kinks.

Cost overruns and a political scandal have blackened the image of the next IGCC likely to start up: a 618-MW plant in Edwardsport, Ind., that could begin operating later this year, one year behind schedule. Last year Duke Energy, based in Charlotte, N.C., sought state approval to charge Indiana ratepayers US $2.7 billion for the project, whose construction budget has ballooned from $1.9 billion to $3.3 billion since work began in 2007. Allegations of improper lobbying have prompted the firing of several Duke executives and the indictment of Indiana's top utility regulator on four counts of "official misconduct." In April the utility trimmed its request to $2.6 billion and took a $420 million loss on its balance sheet.

Critics of coal-fired generation see even on-budget IGCC as a poor investment, citing environmental liabilities. Sulfur and heavy metals captured by the plant must be disposed of, and opponents question whether sequestering captured carbon underground will prove technically viable and socially acceptable. If it doesn't, such plants could face penalties under future carbon markets and regulations.

"In our opinion, they're investing in the wrong technology. You're much better off building infrastructure that's proven, like wind or solar power," says Andrew Behar, CEO of As You Sow, a nonprofit shareholder-action group based in San Francisco that challenged Duke Energy's investment strategy at the firm's annual meeting in May.

China may ultimately offer more fertile ground for IGCC technology and carbon sequestration. Despite an aggressive shale-gas production program, replacement of coal by natural gas is hard to imagine in China. As Friedmann puts it, "There's just not enough gas. If China gets everything they want in natural gas, they may decide not to build 100 000 MW of coal generation over the next five to eight years. But they will still build 400 000." —PETER FAIRLEY

hands on

LASER CUTS PAPER

A recycled DVD laser makes a great engraving tool

TODAY'S HIGH-SPEED DVD drives have less than 40 nanoseconds to heat a bit position on a disk to its phase-change temperature, so anything that stays in the laser's focus longer had better watch out—or prepare to be burned.

Thus was born the cheap diode-laser cutter and engraver: Get yourself an *x-y* carriage, a couple of stepper motors, a laser driver circuit, and a controller, and presto! You have an almost powerless, albeit very slow, cousin to the big laser cutters that have revolutionized small-scale flat-pack design and manufacturing.

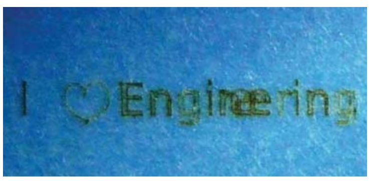
But wait, there's more—or rather less. A DVD drive already has a perfectly usable small stepper motor built in, along with guide rods that provide very precise single-axis travel. Mount two of them at right angles and you have the guts of a laser engraver that could fit in a very large pocket.

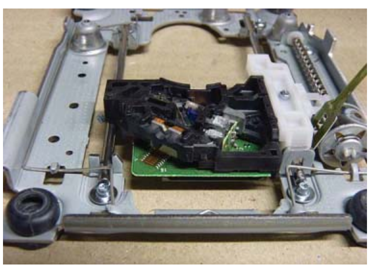
So I fired up my browser, read a real hacker's description of how to do this at Instructables, and headed out to build my own, only to find that technology advances in sometimes inconvenient ways. First, I went to the local used-computer store, the one that used to have stacks of dead machines on pallets out back. No drives. Ever since e-waste recycling became the rule, none of the old hardware stays more than a month. I could call back and see when they got a burner-equipped machine in for scrap, but no guarantees.

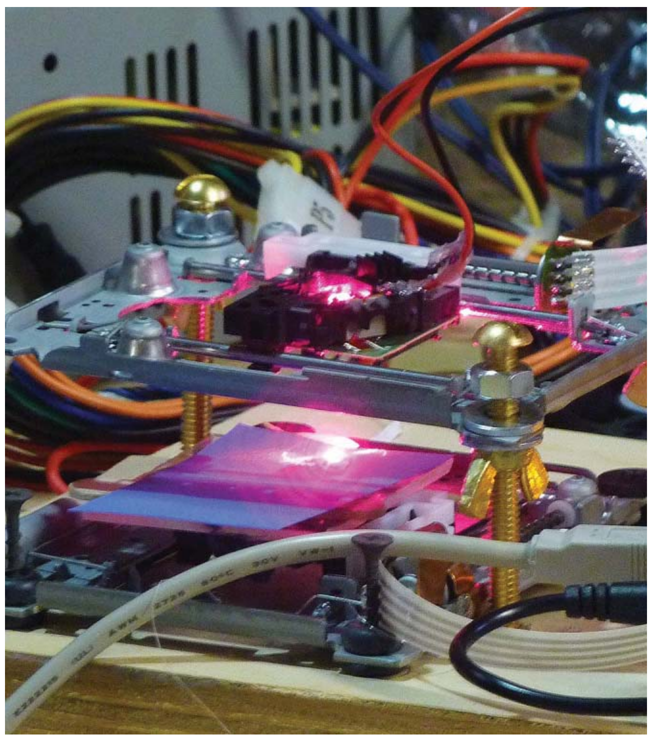
With the fastest-rated burners going for US $22 each online, this was no great burden. But when my order came in, I found that the drives had a designed-for-manufacture mash-up of diode, heat sink, and circuit board instead of the easily removable diode module of years past.

After breaking the first diode I pried out, I decided to reuse the next one in place, including most of the optics. For best cutting it would have been nice to keep the close-focus secondary lens, but it was a Rube Goldberg marvel suspended by springs and magnets, with fine-positioning coils and a servo loop closed by image processing—in short, something I'm not up to hacking. So I finally left the primary lens in place and hot-glued another primary (pried out of the other axis carriage) on top of it.

I also went with a commercial laser driver circuit from AixiZ and a couple of cheap stepper drivers from SparkFun. Sure, the same circuitry might be available somewhere on the drives' circuit boards, but finding it and convincing it to work







PAUL WALLICH (4)

LASER BURN: It takes 20 minutes to strip the metal frame and laser carriage out of a DVD burner [bottom left, center left], and an hour or two to clear excess parts from the carriage and wire the diode and stepper motors to external drivers controlled by an Arduino microcontroller. The 150-milliwatt red laser [above] has just enough power to burn paper or melt plastic. Optimizing focus, burning speed, and power to get consistent engraving is a trial-and-error process [top left]. A power error can quickly send you back to the surplus bin for a new diode.

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careers

for me instead of against me seemed like too much trouble.

With this cobbled-together bunch of hardware, building the software to burn images would seem to be fraught with trouble. It's not. More than 30 years ago, engineers in the computer numerical control (CNC) machining business standardized something called G-code—essentially a virtual-machine assembly language for numerically controlled tools. And what's a laser engraver but a numerically controlled milling machine with no *z*-axis and a very fine bit?

G-code is the lingua franca of the do-it-yourself CNC community, so of course a small cluster of hackers—in Norway, as it happens—has written a customizable G-code interpreter, called Grbl, that runs on an Arduino microcontroller. Tell it how far one pulse of your steppers should move your tool head, how fast to pulse the steppers, which pins everything is attached to, and a few other parameters and it does the rest. With free G-code generator extensions to various drawing programs, sending a page to an engraver is only slightly more complex than sending it to a regular laser printer.

It's a little bit frightening just how straightforward it is to get all these disparate pieces to work together—and to think of the power lying untapped in discarded computer parts. I can hardly wait till Blu-ray drives (up to a watt of easily absorbed short-wavelength light) start coming up surplus.

—Paul Wallich

HEC PARIS

MBAs in Europe

Europe's top business schools are less expensive and more worldly than their U.S. counterparts

When it comes to a master's degree in business administration, the United States boasts 5 of the world's top 10 business schools. But schools on the other side of the Atlantic are giving American schools a run for their money, quite literally. For those seeking a truly global experience in a lustrous program—without shelling out quite as big a fortune—Europe has become an MBA mecca.

European business schools offer a truly international experience, invaluable in today's business world. Roughly 90 percent of students in top European schools come from abroad, compared with 35 to 40 percent for U.S. programs. "European schools believe that a mixed international cohort makes for a better learning experience and better reflects international business," says Stephen Hoare, a journalist and communications agency director who specializes in MBA and postgraduate education.

When it comes to value for money, U.S. programs fall to the bottom of the *Financial Times*'s 2012 ranking of full-time MBA programs, largely because they take two years to complete, while yearlong programs are common in Europe. Tuition and fees for a top full-time U.S. MBA program can leave you with a debt of US $120 000. Total costs for Europe's finest—the programs at London Business School and France's INSEAD—are about $85 000 and $72 000, respectively.

To be sure, most engineers get an MBA for a career change, whether to move into management, change industry, or become entrepreneurs, and one advantage of a two-year program is that students get a chance for a summer internship. "For an engineer who's changing careers, or wants to, [an internship] can be very valuable," says Dan Bauer, the managing director and founder of the MBA Exchange. Whether that's worth the additional cost and time is a personal decision. *IEEE Spectrum* put together this list of programs in Europe that stand out, based on several different published rankings—including those by the *Financial Times* and *The Economist*—and after speaking with consultants and other experts.

In the end, most students, be they engineers or not, American or Asian, are looking for the same things when they choose schools, Bauer says: "A prestigious brand and a location that will not only be satisfying to live in while attending school but also beneficial after school." —Prachi Patel

CAREER CHANGE

London Business School

Tuition and fees: US $84 623 *Average salary:* $152 981
Located in a pulsing capital of the world, the London Business School gives a truly global experience. The flexible full-time program can be completed in 15, 18, or 21 months and offers the best of the North American and European models. Another strength is its vast alumni network spanning more than 120 countries.

International Institute for Management Development, Lausanne, Switzerland

Tuition and fees: $92 019 *Average salary:* $144 045
At just 90 students, this is a small program, but alumni rate it most effective at landing stellar jobs for its grads. They also report the highest satisfaction for achieving their goals, whether it's a career change or networking. According to *The Economist*, the school has superb global business contacts and gets healthy support from its corporate partners.

Special mention: IESE Business School–University of Navarra, Barcelona; INSEAD in Fontainebleau (France), Singapore, Abu Dhabi, and United Arab Emirates

STRONG TECHNOLOGY FOCUS

Cranfield School of Management, Cranfield University, Cranfield, England

Tuition and fees: $53 800
Average salary: $125 196

Warwick Business School, University of Warwick, Coventry, England

Tuition and fees: $41 000
Average salary: $118 151

Cranfield and Warwick boast strong ties with industry and to parent universities that are leaders in science and engineering education and research. A majority of graduates from both schools go on to work in the IT/telecommunications field. Both programs are quickly moving up and taking their places among the best in Europe.

Judge Business School, University of Cambridge, Cambridge, England

Tuition and fees: $55 650 *Average salary:* $132 758
You can't beat ties with one of the world's oldest and most prestigious universities. Then there's the invaluable proximity to the "Silicon Fen" region around Cambridge, which is home to a cluster of high-tech businesses.

Special mention: Grenoble Graduate School of Business, Grenoble, France, for its lower tuition and fees ($35 625) and opportunities to specialize in such areas as innovation management and biotechnology.

CALLING ALL ENTREPRENEURS

Saïd Business School, University of Oxford, Oxford, England

Tuition and fees: $63 898
Average salary: $134 805
Entrepreneurship is a leading area of study at Oxford and one that's top-rated by alumni. As *The Economist* puts it, "the Oxford 'brand' is a huge attraction, particularly in North America. And brand names matter when you're planning to venture out on your own."

Special mention: International Institute for Management Development, Lausanne; Judge Business School, Cambridge

A UNIQUE EXPERIENCE

HEC Paris

Tuition and fees: $65 234
Average salary: $121 061
Getting into this highly selective program is tough, but once you're in, you'll be on a large, modern campus an 18-kilometer train ride from central Paris. The school takes pride in French culture, and learning the language is a requirement. A win-win for those seeking professional and personal fulfillment. *Special mention:* ESADE Business School, Barcelona; IESE Business School–University of Navarra, Barcelona

Sources: Bloomberg Businessweek, *"Business School Comparator" (Tuition and fees)*; "Financial Times, *"Global MBA Rankings 2012" (Average salary)*

THE PATENT ELIGIBILITY BAR GETS RAISED AGAIN

Yet, for the fourth time in 150 years, the Supreme Court fails to clearly distinguish between an invention and an idea

PUT YOURSELF in the year 1850. You've just discovered electromagnetism—the idea that current in a wire produces a magnetic field. In quick succession you invent an electromagnet (a coiled wire wrapped around a nail and connected to a battery), a telegraph system employing the electromagnet, and finally, a rudimentary electric motor, including permanent magnets on a rotor and electromagnets fashioned as a stator.

For which of these are you entitled to a patent? Few would seriously dispute the eligibility of the motor and the telegraph. But what about the electromagnet? Wouldn't it be nearly the same as patenting electromagnetism itself?

This problem has confounded the courts since, well, the days of Samuel Morse. He tried to patent the use of electromagnetism to make or print characters, signs, or letters at a distance. No, said the U.S. Supreme Court in 1853—that's trying to patent an idea instead of an application of an idea.

Ever since, the issue of what exactly is patentable has remained unresolved.

Jump ahead a hundred years to the first patent filings for software. With two early decisions, the Supreme Court confused inventors further by seeming to contradict itself. In *Diamond v. Diehr* (1981) it held that a computerized method that employed an equation used in curing rubber was patentable. But in *Parker v. Flook* (1978), a computer-implemented method employing a formula to update alarm limits in a catalytic conversion process was not patentable. The two cases are, to say the least, difficult to reconcile, and once again the line that separates unpatentable abstract ideas, laws of nature, formulas, and equations from patentable applications of laws of nature and implementations of an idea remained undrawn.

Let's jump ahead once more, to the patenting of business methods. In 2008, an appellate court devised a new test to decide where the line was to be drawn. But two years later the Supreme Court held that this test was not definitive: In *Bilski v. Kappos* (2010), the high court held that patent claims that failed the test might still constitute a patentable invention. And yet, the court raised the patent eligibility bar, at least for some business methods, by striking the *Bilski* patent application.

Enter now patents for medical diagnostic procedures and genetics. Last month, the Supreme Court reviewed a patent covering a method that correlates metabolic concentrations in a patient's blood with predetermined thresholds, helping a physician determine whether to increase or decrease the drug dosage that led to the metabolites forming in the blood in the first place. Not patentable, held the court:

> *To put the matter more succinctly, the [patent] claims inform a relevant audience about certain laws of nature [metabolites produced because of the drug]; any additional steps consist of well understood, routine, conventional activity already engaged in by the scientific community; and those steps, when viewed as a whole, add nothing significant beyond the sum of their parts taken separately. For these reasons we believe that the steps are not sufficient to transform unpatentable natural correlations into patentable applications of those regularities.*

In other words, a process that, as the court put it, "amounts to no more than an instruction 'to apply the natural law,'" is no more patentable than natural laws themselves. Like *Bilski*, this case could narrow the realm of the patentable—indeed, it could lead to patents for genetic material being held invalid.

The upshot is that, even after 150 years and four huge waves of innovation, it's still hard to differentiate between an idea or a law of nature and an application of the same. And it's a problem that spans all fields—electromagnetism, software, business methods, medicine, and more.

In fact, the problem is utterly pervasive. Everything is built on or operates according to at least one natural law, and everything stems from some kind of an idea: That current in a wire produces a magnetic field is a law underlying the idea behind many products.

Vagueness and ambiguity are a patent attorney's stock in trade, but I feel for inventors, who need some kind of clarity when it comes to drawing the line between what is and isn't patentable.

—KIRK TESKA

KIRK TESKA is a partner of Iandiorio Teska & Coleman, an intellectual property law firm in Waltham, Mass.

RICHARD MIA

first look

Smart Bullets

It was just a matter of time before smart-bomb technology got small

A TEAM OF engineers at Sandia National Laboratories, in Albuquerque, is completing a testable prototype of the world's first laser-guided bullet. Like a "mini-me" of smart bombs, this patented technology has some of the same computerized control and guidance features found on proven Gulf War weaponry, such as the Paveway series of laser-guided bombs.

An infrared laser illuminates a target, which the bullet's optical sensors follow. An onboard tracking chip calculates the course corrections, carried out by four actuator-controlled fins on the bullet's body.

The end result, says Larry Shipers, manager of system technologies at Sandia, is a bullet that could improve its shooter's marksmanship by 98 percent, at distances between 1 and 2 kilometers.

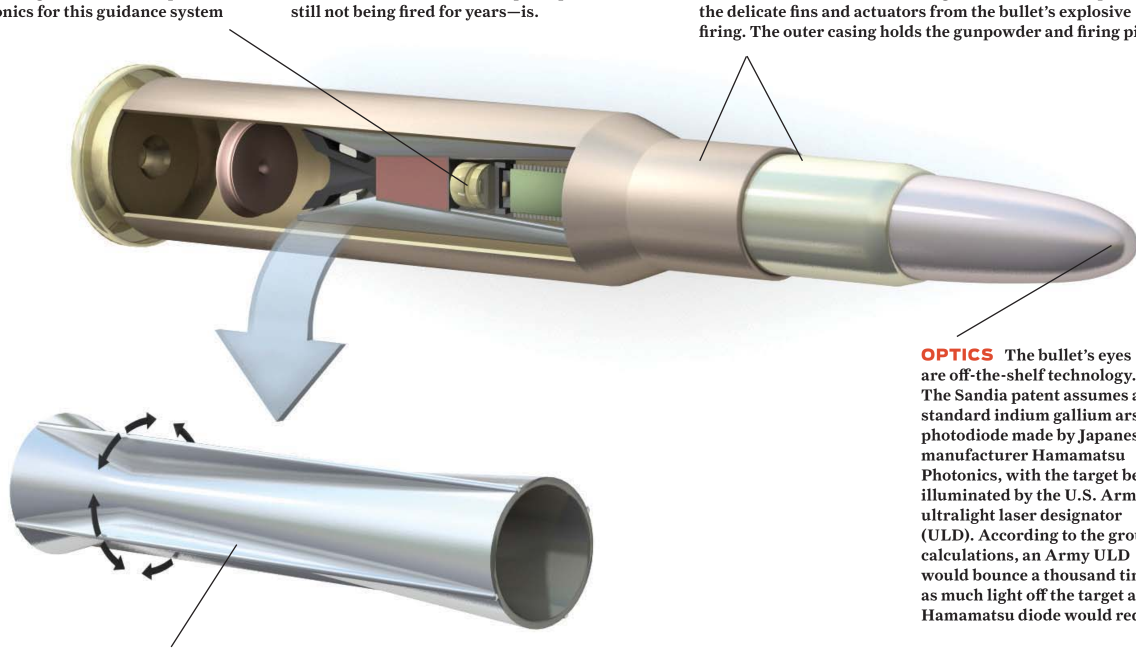
Shipers says the technology has already cleared a hurdle that experts had said couldn't be overcome: the survival of the battery and chip, despite their being fired out of a .50-caliber rifle. Launch tests found that the munition's innards did indeed stand up to the crushing 120 000 *g*-force acceleration and 344.7 megapascals (50 000 pounds per square inch) of pressure as the bullet comes hurtling out of the barrel. The next step is to find a commercial partner that can turn the ideas now being bench-tested into a field-ready bullet.

"We believe we can get to a full-up prototype using primarily existing technology," says Shipers.

—Mark Anderson

COMPUTER AND BATTERY When the smart bullet is fired, dry electrolytes in the existing lines of "shock activated" batteries turn molten and can readily provide the bullet with its 5-milliwatt-hour energy budget over the projectile's 5-second flight time. The simple electronics for this guidance system were first designed in the 1970s for early-generation smart bombs. Larry Shipers of Sandia Labs says that miniaturizing the electronics to fit the bullet isn't the challenge; making a whole system that can survive real, extreme battlefield conditions—while perhaps still not being fired for years—is.

CASING AND SABOT Rifles—firearms with grooved barrels that impart a stabilizing gyroscopic spin to the bullet—have been the standard military weapon for more than a century. But Shipers said his group had a "back-to-the-future moment" when they realized that without rifling—as in the muskets of the Napoleonic wars and before—bullets would be steerable. The solution: two levels of casing. The inner "sabot" protects the delicate fins and actuators from the bullet's explosive firing. The outer casing holds the gunpowder and firing pin.



OPTICS The bullet's eyes are off-the-shelf technology. The Sandia patent assumes a standard indium gallium arsenide photodiode made by Japanese manufacturer Hamamatsu Photonics, with the target being illuminated by the U.S. Army's ultralight laser designator (ULD). According to the group's calculations, an Army ULD would bounce a thousand times as much light off the target as the Hamamatsu diode would require.

FIXED AND MOVABLE FINS Because it's not spinning, the bullet must have its own aerodynamic stability. So the Sandia design makes it work like a rocket. A counterweight near the nose (made either of tungsten or depleted uranium) pushes the bullet's center of gravity ahead of its center of aerodynamic pressure. Rocket engineers use the same trick. Also like a rocket, the smart bullet has its own fixed tail fins to keep its trajectory true. However, many times a second, the computer chip sends instructions to its four actuators, which can move a corresponding movable fin to one of three positions: straight ahead, displaced 3 degrees one way, or displaced 3 degrees the other. The bullet is maneuverable enough to overcompensate in one direction and still find its way back to a trajectory closer to the target.

ILLUSTRATION: EMILY COOPER; SOURCE MATERIAL: SANDIA NATIONAL LABORATORIES

technically speaking

BY PAUL McFEDRIES

Consumption 2.0

Zipcar's predicate is that sharing is to ownership what the iPod is to the eight-track, what the solar panel is to the coal mine. Sharing is clean, crisp, urbane, postmodern; owning is dull, selfish, timid, backward. —Mark Levine, *The New York Times Magazine*

HAVE YOU noticed that as we **dematerialize** consumer goods (that is, change their atoms to bits), we're less likely to own them? Businesses like iTunes have furtive terms of service that turn out to merely license the music you think you're buying. And then there are fee-based services that forgo media ownership entirely, such as Spotify. As visionary and *Wired* cofounder Kevin Kelly puts it, "Access is better than owning."

That sentiment is the driving force behind a new economic model called **collaborative consumption**, where consumers use online or off-line tools to rent, share, and trade goods and services. Some people refer to it as **Zipcar capitalism**, from the eponymous **car sharing** service wherein subscribers—who apparently without irony call themselves **Zipsters**—rent vehicles by the hour.

While Zipcar is an example of a business-to-consumer (*B2C*, in bizspeak) model, the real action in the **sharing economy** revolves around the new consumer-to-consumer (*C2C*) models. For example, if you're not going to be using your house or apartment for a while, you might think about renting it out. In the past, this involved a huge **hassle factor** (the costs and time that it takes to find customers) and the ever-present **stranger danger** (the risk that your renter might trash your place). Fear not! **Collaborative travel** services (such as Airbnb) match you with prospective renters and take steps to ensure the safety of your abode.

This is called **peer-to-peer consumerism,** and its marketplaces include **tool sharing** (borrowing tools stored in a **tool bank** created by a community); **couch surfing** (booking accommodation with a local resident when you travel to a city); **coworking** (renting space in a workplace); **cohousing** (a community of private residences that includes shared facilities co-owned by the residents); and **social lending** (loans without a bank as intermediary).

One of the main ideas behind this new **rentalism** is the concept of **idling capacity**, which is the untapped economic and social value of underutilized assets. For example, most cars sit in a driveway or parking lot much of the time, so why shouldn't owners use a **social car sharing** service (such as Getaround or Zimride) to rent them out? More generally, this is known as **peer-to-peer rental,** and companies such as SnapGoods and Zilok are pairing people who temporarily need stuff and people who have that very stuff sitting idle.

Another aspect of collaborative consumption is to extend the idea of the *time-share*, already widely used for resort properties and airplanes. A **communal purchase** gives people **fractional ownership** of other expensive items as well. Two similar ideas are the **group coupon** (also known as a **groupon**, after Groupon.com), which is a consumer discount that applies only if a minimum number of people sign up for the deal, and **crowdfunding**, which involves getting projects funded if similarly large numbers of people commit themselves. Kickstarter is the most popular such tool, hence the term **Kickstartup** for ventures funded by the site. Then there's the **carrotmob**, where people gather en masse to support an environmentally friendly store by purchasing its products. (The word is derived from *flash mob*, discussed in these pages back in 2003.) My favorite communal purchase idea is **cowpooling**, purchasing a whole cow or side of beef from a local farmer.

The rise of collaborative consumption was probably impossible without social networks. According to Rachel Botsman, coauthor of *What's Mine Is Yours* (HarperBusiness, 2010), collaborative ventures depend in part on **social proof**, the validation of a service or business that comes from seeing others use it and talk about its benefits. Collaborative consumption also depends hugely on the **reputation trails** we all leave behind us that say how trustworthy we are. So collaborative consumption offers a vision of an economy that is more open, more trusting, and more sustainable. Sounds good to me. Bring on the cowpools! ❑

GLUEKIT

SPECIAL REPORT

The Beginning of THE END OF CASH

Cash's role is waning, as mobile, encryption, and other technologies let us plug directly into the digital economy

BY GLENN ZORPETTE

PHOTO: LEVI BROWN; PROP STYLIST: ARIANA SALVATO

PHOTO: LEVI BROWN; PROP STYLIST: ARIANA SALVATO

THE BASIC PARADIGM HAS BEEN IN EFFECT for years. You toil, scheme, cajole, and cogitate, and in exchange you get paid—but probably not in cash. Some bits get altered periodically in a database somewhere, as infinitesimal patches of ferromagnetism on disks or electromagnetic pulses flitting from here to there. Your earnings, your savings, your spending: Virtually all of it is virtual.

Money is the most important abstraction human beings have ever devised. And yet that abstraction has not been fully embraced. Decades after money began going electronic, we all continue to cling to cash, a quaint vestige from earlier eras when money meant cowrie shells, giant stone disks, and shiny gold pieces. Of the many things we could do now with technology, getting rid of cash would be one of the more sublime.

But various factors and factions continue to prop up the cold hard stuff. One is the awesome might of the middle-aged and elderly. Says Ron Shevlin, an analyst with the Aite Group (and Monty Python fan): "There are a lot of baby boomers who aren't dead yet, and they're simply not going to give up cash." Cash will gradually die off as, well, they do, he says.

Weaning ourselves away from cash is a good idea, Shevlin adds, but let's be realistic. The world he and his colleagues envision has robust and convenient alternatives to cash, but it has cash, too. "That's why we call it the less-cash society, not the cashless society," he says.

It's not just baby boomers who can't let go of cash, though, and that fact reveals some interesting things about us. First, we're kind of lawless, and we'd rather the government didn't know everything we do. Anarchists, drug dealers, prostitutes, politicians, dog walkers, and nannies all have reason to prefer cash. There's a big, spinning world of under-the-table transactions, and what makes it go round is cash. The most thorough recent attempt to measure a country's underground economy was in 2011 by the U.S. economists Richard Cebula and Edgar L. Feige. Their study concluded that 18 to 19 percent of the total reportable income in the United States is either not reported or not properly reported. The researchers estimated that the tax not paid came to half a trillion dollars in 2008.

But even if you've got nothing to hide (*nothing*? really?), cash is still undoubtedly part of your world. Would you want to pay for a banana with a credit card, even if you could?

For most of us, cash has become a smallish but unavoidable expedient in our lives, like umbrellas or paper towels. And that smallish role is going to get even smaller, because cash is under assault on multiple fronts. The strange world of money is about to get a lot stranger.

Established alternatives to cash include cards: credit, debit, and more recently, prepaid debit. There is also a growing assortment of marginal electronic alternatives, such as the scrip that gets passed around in online games and social networks.

More interesting and much more ambitious are the cryptocurrencies, chiefly Bitcoin, which is backed by no government and has a fluctuating value linked in part to a scarcity that is mathematically predetermined. Unlike other forms of digital cash, Bitcoin is truly untraceable and therefore, like cash, cannot be recovered if lost or destroyed.

The biggest near-term threat to cash, though, will come from mobile payments. All over the world, the push is on to get you to use your cellphone to buy stuff. The United States has lagged badly here, but with Google's considerable muscle, it is now attempting to catch up. In these mobile payment schemes, your phone simply stands in for your credit card, storing its data and communicating with a merchant's little credit card terminal via a radio technology called Near Field Communication. Following Google's example, which is called Google Wallet, Verizon, AT&T, T-Mobile, and others are now rolling out competing schemes that will let you buy that banana by waving your phone near that terminal. Well, probably not the banana, because these systems all depend on your phone pretending it's a credit card, and credit cards are still far from universally welcome for banana-size transactions.

Google and its rivals are reportedly trying to rectify that situation. Google, in fact, until recently harbored ambitions of becoming a mint—literally, in addition to figuratively. "We had various proposals to have our own currency, which we were going to call Google Bucks," said executive chairman Eric Schmidt during a Q&A at the Mobile World Congress 2012 (a YouTube video is available). The idea was abandoned, Schmidt said, because of "some issues with peer-to-peer money. It turns out that it's in most cases illegal....The reason that it's illegal is that governments don't trust it because of the issues of money laundering and so forth, and the central banks want to control it."

Anarchists, drug dealers, prostitutes, politicians, dog walkers, and nannies all have reason to prefer cash. How about you?

So there are rivers of cash that not even Google can get at (at least for now), and not all of it is extralegal: You pay the babysitter; you stuff a few bills into your nephew's birthday card; maybe you tip your masseuse. And all of those day-to-day transactions add up to a surprisingly large category. A study by the Aite Group estimated that cash transactions in the United States totaled US $1.2 trillion in 2010 (not including extralegal ones, of course). Eighteen percent of that total was people paying bills, roughly 43 percent was retail purchases (such as your banana), and a whopping 40 percent was direct payments from one person to another. Small, cash-out-of-the-pocket exchanges are still the stuff of everyday life.

There will come a day, however, when you'll be able to hold your cellphone next to someone else's, hit some soft keys, and money will be transferred between the two accounts—no credit card required. Indeed, this past April, the government of Canada announced a digital cash initiative based on an integrated circuit called MintChip. The idea is to let people make their small transactions by exchanging information from those chips via their smartphones and other appurtenances. And unlike Bitcoin, the money transferred would be a national currency—Canadian dollars. But analysts question whether it would be as truly anonymous as real cash.

Together, these mechanisms will shrink cash's niche still further. In the articles that follow, we describe the various ways that technology is transforming the nature of transactions and altering the way we interact with the vast, swirling digital economy that already pervades our lives: how it is rewriting the schemes by which we pay for stuff; how it is shaving microseconds off futures-market trades; how it is boosting security by linking our biometric selves with our accounts. How it could, in theory, finally achieve an ancient ideal: money that cannot be counterfeited.

These and other advances will bring changes as fundamental as did the invention of paper money, many centuries ago. Money will keep doing what it always has—settling accounts, storing value, and greasing the wheels of progress. But it will finally be doing it in a way commensurate with the world it helped create. ❑

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Let a Thousand Currencies Bloom

Technology will free money from government control

BY DAVID G.W. BIRCH

SCIENCE-FICTION WRITERS ONCE IMAGINED a galactic currency that would grease the wheels of commerce from here to Alpha Centauri. In fact, however, we are tending in precisely the other direction, toward a burgeoning number of ever more specialized currencies. These will circulate electronically, by means of the mobile phones that are increasingly part of the dress of every person on the planet.

Seemingly everywhere you look, you can see the emergence of this pattern in what futurologists call the weak signals of change. These are the changes that will be seen, a generation from now, to have foreshadowed a technological revolution.

That money is a technology is obvious, once you look at it. It is not a feature of the natural world but rather a constructed tool, one that defines a way of doing things. It is a clearly specified standard, like the Internet Protocol, the gauges used in rail transport, or the octane specifications of gasoline. And it can change.

What's more, like all technologies, money exhibits the law of unintended consequences. The historian David Edgerton wrote in *The Shock of the Old: Technology and Global History Since 1900* (Profile Books, 2006) that as

HARRY CAMPBELL

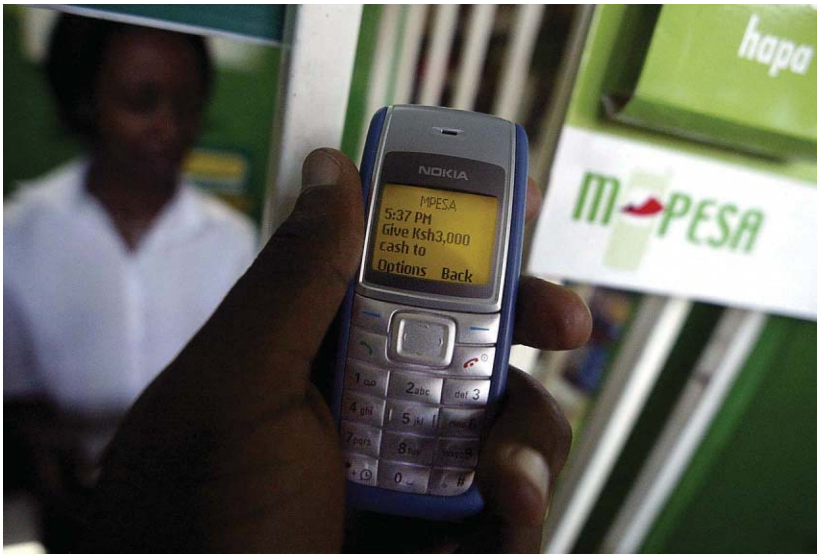
a technology moves through a culture, its downstream uses are often very different from what its inventors had imagined. This fact stands squarely in the way of anyone who would claim to see just where a new technology will take us.

Today, the technology of money is racing to catch up to social changes that have radically altered how people interact and therefore how, why, and when they use money. It's impossible to say what the unintended consequences of these innovations in financial technology will be; we can only note that they will come, and make some intelligent guesses. I believe, though, that in the end, money as we know it will be turned on its head, and this revolution will be at least as profound as the introduction of paper money a millennium ago.

OF COURSE, society has been through times of innovation in monetary technology before. Consider the "split tally," a wooden stick used to record royal taxes in England. Tallies came into use shortly after the Norman invasion of 1066 and were not withdrawn until 1826 (we Brits are a conservative bunch). The sheriff would collect the taxes based on tax assessments and then remit the collected cash to the king. To ensure that both the sheriff and the king knew where they stood, the tax assessment was recorded by cutting notches in a wooden twig. The twig was then split, so that the king and the sheriff each had a durable record of the assessment. When it was time to "tally up," the sheriff would show up with the cash and his half of the tally to be reckoned against the king's half.

The technology worked well. The sticks were small and long-lasting (very long—some of them still exist), they were easy to store and transport, and they were easily understood by those who couldn't read (which was almost everyone, in the early days). They were also secure: Neither the sheriff nor even the king could forge one half of the stick without having the other half.

The tally was soon finding unforeseen uses. The king often couldn't wait until taxes fell due; he wanted his cash as soon as possible (generally for wars with the French or the Scots). So he would sell his half of the stick at a discount. The buyer could then get the cash when the taxes fell due. This made that half of the tally stick, in effect, a fixed-term government bond. The market for tallies evolved quickly. Say someone in Bristol held a tally for taxes due in York; to collect the payment, he'd either have to travel to York or find someone else who would do the job for him, for an appropriate discount. Thus a money technology intended only for record keeping evolved into a thriving market.



TALLY STICKS: These symbols of tax obligations to English kings [opposite page] later functioned as money and as a sort of fixed-term government bond. The mobile phone is the new tally stick. The M-Pesa system in Kenya [above], like the tally stick, is being used in ways its originators never dreamed of—for instance, to safeguard a shopkeeper's cash overnight or buy insurance for livestock.

PHOTOS: OPPOSITE, SSPL/GETTY IMAGES; ABOVE, TONY KARUMBA/AFP/GETTY IMAGES

THE MOBILE PHONE IS THE NEW tally stick. It will evolve in unforeseen ways, and both the push exerted by the new technology and the pull exerted by society's changing needs will shape the outcome. And the result, I believe, will be revolutionary change.

In Japan and Korea, mobile phones have been used for payments for a decade, and the technology is now a standard feature there in handsets. In March, one out of six Japanese users bought something in a shop using a mobile. People also use the system to pay bills and transit fares; businesses use it to funnel loyalty rewards to customers. At first, the number of retailers accepting the new technology remained flat; once about a third of consumers were using it, though, things started to take off, producing the "hockey stick" adoption curve that we technologists love.

What's happening in Africa is even more astonishing. Kenya is now home to the world's most expansive mobile payments scheme, M-Pesa. (I should disclose that my employer, Consult Hyperion, provided paid professional services for the M-Pesa project.) It was launched in 2007—not by a bank but by the country's biggest mobile operator, Safaricom, with support from the United Kingdom's Department for International Development. The system's nearly 15 million users can use their mobile phones to deposit cash into their accounts, using as a point of deposit any of the 28 000 shops around the country that participate. Users can then move their deposited money about with an application built on top of the text-messaging function of their phones. When they want to buy something, they just text the money to another person, shop, or bank that is also in the system; money is then debited from the payer's account and credited to that entity's account.

A third of Kenya's gross domestic product now flows through M-Pesa, and an amazing range of new businesses have sprung up to use it, none of which were envisaged by its founders. Farmers buying insurance to take animals to market, bars that operate cash free (and therefore robbery free), shops that use it as a kind of "night safe," savings accounts that can be accessed only from online—all these have been made possible by the new tally stick.

One reason it has taken off so splendidly is that so many people in Kenya lack credit cards and bank accounts. To send cash to a relative in a far-off village, you might have to pay a courier to take it there—for a tremendously high transaction cost. The proof was in the service's growth: Within a year of its launch in 2007 it had 5 million subscribers, more than all 43 of Kenya's commercial banks put together. The M-Pesa network is now being replicated in Tanzania, Uganda, and other countries.

THE REST OF THE WORLD IS starting to move. In the U.K., the Payments Council—a coordinating body for the financial industry, set up in 2007 by government order—has begun working on a national mobile payment infrastructure. In France, mobile phone operators and banks have gotten together to launch a system for mobile proximity payments, which lets a chip-bearing platform transfer money when held close to the reader. In Germany, meanwhile, the mobile phone operators have decided to ignore the banks and go it alone. In the United States, Google is working with Sprint and MasterCard to launch Google Wallet, while AT&T, Verizon, and their partners are planning a rival called Isis Mobile Wallet (although the U.S. market is a tough one—see "Phone-y Money," in this issue). Other mobile money schemes are hatching in Mexico, Russia, Vietnam, and elsewhere.

All this activity has people once again talking about a cashless society. Because let's face it: Cash is expensive. In the United States, for instance, studies indicate that maintaining

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a cash system—including printing new bills, recycling old ones, moving them about in armored trucks, using them to replenish automatic cash machines—costs the country about 1 percent of GDP. Those studies also show that the marginal cost of a cash transaction is around double that of a debit-card transaction.

Cash's indirect costs are huge, too. In a 2011 study, Edgar L. Feige of the University of Wisconsin, in Madison, and Richard Cebula of Jacksonville University, in Florida, found that in the United States 18 to 19 percent of total reportable income is hidden from federal tax men, a shortfall of about US $500 billion. The Justice Department estimated in 2008 that secret offshore bank accounts were responsible for about one-fifth of the tax gap, suggesting that the remaining 80 percent is attributable to unreported cash.

The need to get beyond cash has been recognized in a number of countries. In the Netherlands, there are commercial streets that are cash free, and many supermarkets have cash-only lanes that are open for just part of the day. In Sweden the government and labor unions have come together to start reducing the amount of cash in circulation. The labor unions want to remove cash from shops and banks because it is their members who get beaten and shot in robberies; the government wants to reduce the burden of police work.

Thus the allure of the mobile phone as an alternative to cash. The enabling technology has finally arrived, and it's taking root because the business drivers (that is, the high cost of cash) and the social drivers (cash's disproportionate cost to the poor) were already there. And just as the plastic card and the Web made it easy for us to pay merchants, the mobile phone will soon make it easy for us to pay each other.

SO LET'S ASSUME THAT THE MOBILE phone will take over and that in a few years' time, you'll be able to pay Walmart or your window cleaner or your niece with your mobile phone. In this world, switching among dollars and euros and frequent-flier miles and Facebook Credits and Google Bucks and any other form of money will be just a matter of choosing from a menu on the phone. The cost of introducing new currencies will collapse—anyone will be able to do it. The future of money, in other words, won't be that single galactic currency of science fiction. (We already know that, because we can't even make a single currency work between Germany and Greece, let alone Ganymede and Gamma Centauri.) Instead, we can look forward not merely to hundreds but thousands or even millions of currencies. And though regulators may oppose the trend, they can't hold it back.

That must sound as crazy to you as the idea of paper money once did to your ancestors, but it really isn't. Trying to imagine a wallet with a hundred currencies in it and a Coke machine with a hundred slots for them is, of course, nuts. But based on the available currencies in your mobile "wallet" and prevailing market conditions, your phone and the Coke machine will be able to negotiate an exchange rate in a fraction of a second.

Likewise, I don't want to carry around a hundred different retailer credit and loyalty cards, but my phone can hold a zillion. So when I go to Starbucks, my phone will select my Starbucks app, load up my Starbucks account, and generally not bother me about the details. When I walk next door into Target, my phone will select my Target app, fire up my Target card, and get down to business.

Who will want to issue these new currencies? Corporations, for starters. When Edward de Bono wrote *The IBM Dollar: A Proposal for the Wider Use of "Target" Currencies* back in 1994, he looked forward to a time when "the successors to Bill Gates will have put the successors to Alan Greenspan out of business," arguing that it would be more efficient for companies to issue money than equity. Even if all I've got is Microsoft Moola, and you want to get paid in Samsung Shekels, who cares? Our phones can sort it out for us.

Other obvious money-issuing entities will be communities that constitute a natural domain for a kind of money—communities defined by region, political jurisdiction, or participation in some activity. In South London we already have the Brixton Pound, a merchant-managed e-currency that's exchangeable for regular pounds. Proponents say it fosters local business; detractors say it puts up an informal barrier to trade. In either case, it demonstrates a degree of local control over money.

THE EFFECTS ON the total supply of money are hard to determine. However, I see no reason why this system would require a central authority to settle up accounts at the end of the day. I would imagine that there will instead be lots of different exchanges settling among different types of currencies.

Such local currencies will follow the decadelong minting of virtual money in various online games, Facebook Credits, and a host of promotions—including some that will no doubt soon become transferable in a way that today's frequent-flier miles are not. These will merge and surge, forming a panoply of private currencies that will give users more ways to pay for things and thus make trade more efficient. Some currencies will excel for transactional purposes, others for economic stability, and perhaps some will just be fun. But in the long term, we will be better off.

The mobile phone will change money forever. It will start by providing a convenient means of exchange, but in so doing it will trigger a new monetary order. That's not a bad thing. It's progress. ❑

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Blood and Money

ATMs in Japan already scan your veins. Is this the first step to a cash-free, card-free world?

BY ELIZA STRICKLAND

ONE OF THE MOST NOTORIOUS ATM SCAMS IN Japan started at a posh golf club in the green hills of Gunma prefecture. In 2004 a ring of thieves that included a club employee installed tiny cameras in the club's locker room to record members typing in their four-digit locker codes. Then, while the golfers were out on the links, the thieves opened the lockers and used "skimming" devices to copy data off the magnetic stripes on club members' bank cards.

The crooks transferred the data onto the mag stripes of blank cards. Then they started testing those cards in ATMs, checking to see how many of the golfers had used the same four-digit number for both their locker codes and their bank personal identification numbers (PINs). The answer: plenty. By the time the police arrested seven members of the gang in January 2005, the crooks had stolen more than 300 million yen (nearly US $4 million) from more than 300 victims.

In an orderly society like Japan, the busting of an ATM-theft ring was big news. And the 2005 golf-club case was one of 801 instances of ATM crime that year—an astounding jump from just 90 in 2003. Shocked by such a rise, the Japanese government

BRYAN CHRISTIE DESIGN

demanded that banks find ways to combat ATM fraud and ordered them to compensate victims from their own coffers. The banks turned to the country's high-tech firms for help, and both Hitachi and Fujitsu came forward. The answer, they said, was already in their hands.

Put one of your hands in front of a bright light and you'll see a web of blue veins snaking up across your palm and into your fingers. That delicate lattice of branching blood vessels is unique to you, just like the striations in your irises or the swirls of skin on your fingertips. Hitachi and Fujitsu have been working for years to commercialize technologies that identify people by their vein configurations.

Now, thanks to their biometric systems, about 80 000 ATMs in Japan are as close to being theft proof as it's currently possible to make them. They've worked so well that the technology is now rolling out worldwide: Major banks in Brazil, Poland, and Turkey have recently integrated Hitachi and Fujitsu's vein scanners into their ATMs, with more to come. In Europe, ATM theft from skimming and other fraud added up to €23 million in the second half of 2010, according to the European ATM Security Team. In the United States, where the simple and relatively insecure mag-stripe card still predominates, ATM fraud and theft is generally assumed to be a far larger problem. Exact figures for global losses are impossible to come by, but Robert Siciliano, an identity theft and fraud expert with the security company McAfee, says that at least $1 billion is lost every year.

Eliminating ATM theft would be impressive enough, but backers of biometrics have grander plans. A few banks are doing away with PINs, while one bold bank in Japan is preparing to let its customers ditch their bank cards. These advances are pushing us toward researchers' most ambitious and futuristic visions, where you'd be able to buy a candy bar or a shirt from a shop just by flashing your hand at a sensor. Such a scheme is still sci-fi for now, and the technical challenges of such a biometric-pay system would dwarf those of ATM-card authorization. But the fact that engineers are starting to tackle those challenges is yet another sign that we're approaching another milestone in human culture: a new level of abstraction in the centuries-old virtualization of money.

RANKS OF SQUAT gray ATMs fill a sixth-floor testing room in the Bank of Kyoto's central operations building. To get into this sanctum, visitors must swipe their temporary security badges at no fewer than six gates, and they're allowed to take in nothing but a pencil and paper. Here the bank's technologists test new applications and security software for their more than 1000 ATMs in and around Kyoto prefecture.

Yuji Kitayama, a managing executive officer of the Bank of Kyoto, ushers his visitors toward the ATMs, which are outfitted with Hitachi's finger-vein scanners. To cope with the ATM fraud epidemic, Kitayama says, Japanese banks all began moving from magnetic-stripe bank cards to "smart cards" with embedded microchips. But the Bank of Kyoto wanted additional security to protect its customers, and its reputation—hence the finger-vein readers.

It's not the showiest technology, but that's a plus. The biometric unit is easily integrated into the machine, and customers don't have to radically change their behavior. After you insert your bank card, you get a screen prompt to place your finger in a plastic notch built into the ATM. Near-infrared light shines from both sides of the notch, and a camera below records the resulting image of the veins in your finger, which is compared to your registered template. If it's a match, the screen displays a confirmation within one second and you can type in your PIN and continue with the transaction. The Bank of Kyoto began the biometric program in 2005, and so far about one-third of its 3 million customers have enrolled in it.

Kitayama explains that once the bank decided to add a biometric system, it methodically compared the possible technologies in terms of security, accuracy, and ease of use. Besides vein readers, other options included fingerprint scanners and voice, face, and iris recognition. A fingerprint reader might have seemed like the obvious choice: The technology is very mature, and fingerprint scanners are cheap and simple to use. The problem is that they're not secure enough. "Fingerprints are easy to fake," says Kitayama. The techniques for lifting prints from surfaces are known even to armchair detectives, and sophisticated crooks can make copies of a print in silicone or rubber.

And if all else fails, hardened criminals have been known to snatch the real fingerprint along with the finger. In a notorious case in Malaysia several years ago, a gang of thieves sliced off a man's finger in order to steal his Mercedes, which used a fingerprint-recognition system for ignition. Such a possibility could make it difficult to get customers on board. "The bank doesn't want to create a dangerous situation for customers," as Kitayama delicately puts it.

Voice- and face-recognition technologies are cheap and easy to use, but nowhere near ready for prime time: A head cold or bad lighting can destroy their accuracy. With iris recognition, a camera examines the intricate microstructures in that part of the eye. Such systems are fairly secure and extremely accurate, but they require users to carefully position their heads and keep their eyes open. This authentication process is also too slow for busy bank customers who want to get cash and get on with the day, Kitayama says.

Vein readers, on the other hand, are fast and accurate. "Finger veins are also

BIOMETRIC BANKING: Fujitsu's palm-vein scanner module [top] and Hitachi's finger-vein scanner [bottom] are both easily integrated into ATMs. This image of a test subject's hand [left], by Fujitsu, shows the pattern of veins unique to that person. The veins, which absorb near-infrared light, appear as dark lines.

PHOTOS, CLOCKWISE FROM LEFT: FUJITSU (2); HITACHI

very difficult to steal," Kitayama points out. Even if a thief were to hack off your hand to fool a vein scanner, he'd have to keep all the blood inside your severed appendage to make it work.

BOTH HITACHI'S AND Fujitsu's systems operate on the same basic principles. The blood flowing through your circulatory system contains the protein hemoglobin, which carries oxygen from the lungs and deposits it in tissues throughout the body. The blood that returns to the heart through the veins contains deoxygenated hemoglobin, which absorbs light in the near-infrared part of the spectrum. The rest of the tissues of the hand, however, allow the infrared light to pass through. So shining near-infrared light on a hand creates an image with shadowy lines where the veins absorb the light.

The two companies' systems differ in the part of the hand they shine light on—Hitachi picked the fingers, while Fujitsu chose the palm. They also use different lighting methods, with Hitachi transmitting light through the fingers and picking up the resulting image on the other side. Fujitsu bounces light off the palm and uses a sensor to record the light that the veins don't absorb, which is scattered through the palm.

At Hitachi, this technology originated in the company's medical-imaging research labs. It then caught the interest of Hitachi's financial services division, where analysts thought it could be useful for banking. But the images produced by the medi-

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cal team's cameras weren't distinct enough to reliably identify individuals, so the challenge finally landed in Hitachi's image processing group. Could they turn this research into a useful product?

At the verdant campus of the Hitachi Central Research Laboratory, on the outskirts of Tokyo, biometric chief researcher Akio Nagasaka illustrates the challenge. He projects an image, faintly mottled, of a ghostly gray finger laced with veins on a screen. "The distribution of brightness on the images tends to be uneven," he says, pointing to thicker parts of the finger that create areas of darker gray. "Typical image-filtering methods are not enough to extract vein patterns," he says.

Nagasaka is cagey about how his team solved the problem—this is proprietary technology, after all. But the journal articles that he and his colleagues have published suggest that they didn't use the method typically used in fingerprint analysis, which compares tiny, distinct features in the print pattern (they're actually called "minutiae"). Instead, to cope with the ghostly grayscale image, the Hitachi team devised a line-tracking method, in which a software program scans the digital image for dark spots and then tries to follow them, pixel by pixel, to see if they form lines. When the program has done that enough times, it yields a pattern of veins.

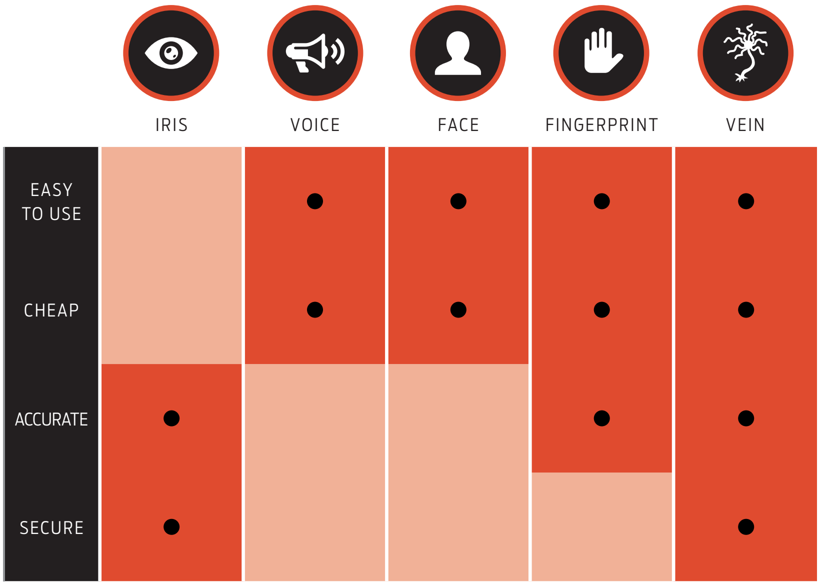
The team has worked to miniaturize the optical system with a CMOS sensor that collects the image; the next-generation sensor they're working on is 15 millimeters long by 10 mm wide, about the size of a woman's thumbnail. The other breakthrough that made the technology commercially viable, Nagasaka says, was the construction of an open-top unit that shines the light on both sides of the finger, with the CMOS sensor below the finger. The banks viewed this module as more user friendly: "You see where you're putting your finger, and you know there's no chewing gum in there," explains Nagasaka.

Besides cleanliness, another serious concern was privacy. Surveys showed that customers didn't like the idea of a bank holding their biometric identifiers in a database. Also, if hackers ever infiltrated that database, the biometric experiment would be over for good for those customers whose accounts were compromised—they couldn't be issued a new set of veins. So Hitachi devised a system called match-on-card, in which the customer's bank card stores the biometric template, and the image taken by the sensor in the ATM is matched to the one on that card. Fujitsu uses a similar system, so customers' biometric information never leaves their control. If the card is stolen, even the most sophisticated hackers would have trouble accessing the biometric data. That's because the cards are configured only to accept incoming data from the ATM's sensor, not to transmit data to an external machine.

WILL WE EVER GET to a day when we can ditch our bank cards, credit cards, debit cards, store-loyalty cards, PINs, driver's licenses, and even money itself—when our vein patterns can be our de facto wallets? Such a move would revolutionize commerce and be fantastically convenient for consumers. Researchers contacted for this story generally furrowed their brows and said such a day is far away. Nevertheless, work now being done at Fujitsu Laboratories looks an awful lot like the first step toward that distant future.

At the lab's Kawasaki headquarters, biometrics research manager Takashi Shinzaki pulls out a boxy device a little larger than a hand. He holds his hand over a notch in the device while pressing three fingers to a green, glowing plate; this allows a tiny sensor in the notch to collect his palm-vein data, while sensors in the plate simultaneously collect three fingerprints. Fujitsu unveiled this "multimodal" system last year.

PAYMENT BY FINGER: At a technology expo, a Hitachi employee shows off a prototype of a biometric-based vending machine. *PHOTO: YOSHIKAZU TSUNO/AFP/GETTY IMAGES*



HOW BIOMETRIC IDENTIFICATION SYSTEMS STACK UP: When it comes to accuracy, face- and voice-recognition systems still have a way to go. In terms of security—the degree to which an identification system can't be fooled by a copy, photograph, or recording—vein and iris biometric systems perform best.

Such a complicated system isn't necessary at the ATMs that currently use vein biometrics. Those systems rely on one-to-one matching, where the data from the sensor is compared only to the one template stored on the user's bank card. That's a relatively easy challenge—the system is just verifying that you are who you say you are. But if you want to do away with bank cards and PINs or use biometrics at the grocery store, you need a system that can compare a customer's data to the templates for everyone enrolled in the program. This is known as one-to-many matching, and it's a much harder challenge. Here, the system has to quickly and accurately acquire your biometric data and then—having no idea who you are—zero in on the one matching template in a database containing millions of possibilities. And it has to do that in a second or two.

Fujitsu has made impressive progress of late. At Fujitsu Labs, Shinzaki's software program sorts through the 5 million templates that are stored for testing and correctly identifies him in 1.34 seconds. "We're working on a system for 10 million people now," he says proudly.

Shinzaki explains how the system gets such quick results: It merges the data from each of his three fingerprints with his palm-vein data and discards all the templates that show a big dissimilarity to any of the fingerprints or the palm data. "With this preselection process we quickly narrowed down from 5 million to 10 000 possibilities," he says. Then a slower, more accurate matching program carefully compares Shinzaki's data to the remaining templates to identify him. This process relies heavily on parallel processing, with the matching tasks portioned out among seven servers at Fujitsu Labs.

Technology isn't the only challenge here. Banks and customers both need a lot of reassurance before they'll agree to entrust their money and biometric details to a futuristic system. All the banks that have adopted biometric systems currently use one-to-one matching; a few intrepid banks, in Turkey and Brazil, have gone so far as to do away with PIN codes. But now one Japanese bank is preparing to take the final leap into a brave world of card-free money withdrawals. In September, the Ogaki Kyoritsu Bank will introduce an ATM system that uses Fujitsu's technology. Customers who enroll will have no ATM card; instead they'll use birth date, palm, and a PIN to access their accounts. In exchange for this convenience, customers have to give up some privacy, because the absence of a bank card means that all those customer templates will be stored in a central database.

Such systems may gradually become more common, the researchers say. At Fujitsu, Shinzaki notes that Japan's triple disaster of 2011—earthquake, tsunami, and nuclear accident—displaced more than 300 000 people, many of whom ran out of their homes in terror for their lives. "Many people lost their cash cards, and they had no identification," Shinzaki says. "If there was a bank service without ID that used only biometric data, the bank could have continued to provide access for their customers."

The Japanese banks did help their customers, Shinzaki adds, even those who could show no identification. "Many banks provided up to 100 000 yen," he says. But in the chaotic aftermath of the disaster, a few unscrupulous people went to the banks and managed to get money they weren't entitled to. A vein-only ID system would have quickly sent those scam artists packing.

If the wider adoption of biometrics depends on convincing banks, this kind of protection against scam artists may be the best selling point. And with Fujitsu and Hitachi both striving to offer faster and more reliable matching, the Japanese may become the first people in the world to let their wallets be part of them, their own flesh and blood. ❑

Write to us at http://spectrum.ieee.org/biometrics0612

THE FUTURE OF MONEY

Cashing Out

My year trying to live cash free. It's harder than you think

BY DAVID WOLMAN

NOT LONG AGO, I was visiting my sister in New Jersey when a last-minute change in plans forced me to hop on a train into New York City without time to prepurchase a ticket. When the conductor came around, I fished my wallet from my back pocket, took out my credit card, and waved it at him.

He glared at me. Then he said two words that made me cringe: "Cash only."

Normally, that wouldn't have been a problem. Like most American commuters, I usually keep a few twenties on me for situations like this one, when plastic just doesn't cut it. But at the time, I was two months into a quest to go an entire year eschewing cash—and I mean not even handling the stuff. I was writing a book on the origins and fate of physical money, and I wanted to get a glimpse of what the cashless future might look like.

Sure, cash used to be king. But no longer. By some estimates, cash transactions account for only 5 percent of the value of all economic activity on the planet, and for good reason. You may think that crumpled €5 note in your pocket is as cheap to produce as tissue paper and as efficient as a handshake—really, who wants to bother waiting for the taxi driver to run your credit card when you can just slip him a ten? But cash comes with costs that are huge, and often hidden. Not only does anonymous paper money enable criminals like drug dealers and tax evaders, but it also takes an army of printers, inspectors, distributors, security guards, cashiers, armored truck drivers, and ATM repairmen just to keep it all in circulation. In the age of trading stocks with high-tech algorithms and deploying smartphone apps at checkout counters, cash is absurdly analog.

But could we ever ditch bills and coins completely?

At first, my cashless life wasn't all that different from my normal life. I still did all my major shopping with credit cards, paid my bills online, and deposited payments directly into my checking account using a bank app on my smartphone that lets me carry out a transaction by snapping a photo of a check's front and back. I steered clear of vending machines, farmers' markets, street merchants, cash-only restaurants, and coin-operated laundry facilities. Not being the type to wear shoes that need shining, call for a bellman, or buy weed in a back alley, I thought that staying true to my no-cash vigil would be as easy as giving up typewriters or pay phones—and figured it would stay that way.

Before long, however, I began to notice instances in my daily economic life where cash has dug in its heels. At my favorite doughnut shop, I was forced to pay the $2.50 charge minimum for an 80-cent buttermilk bar. While out for a jog, I had to give the same sorry excuse to neighborhood kids selling lemonade for a measly 25 cents a cup. Once, while doing book research, I sat in on a Debtors Anonymous meeting. There I was, the man who snubs cash, surrounded by people who had forced themselves to cut up their credit cards. When the meeting ended, someone passed me a plate for donations. Fingering my lean wallet, I sheepishly passed it on as quickly as possible.

My New Jersey train ride marked a turning point in the experiment. I would like to say I tried to bargain with the conductor—offered to paint his house, say, or give him my watch in exchange for a seat on the train. Perhaps I could have even marshaled some kind of argument about the transit system's pathetically limited payment options. But in truth the guy was three times my size, and because I knew I still had some dollars sitting untouched in my briefcase pocket, I gave in. As I guiltily examined the change the conductor placed in my palm, it occurred to me that cash isn't just an anachronism we haul around to make it easier to split a bar tab or pay a babysitter. Every so often, even for a devotedly wired consumer like myself, cash remains a necessity—at least for now.

The real wake-up call came when I took a trip to Delhi. Despite the fact that mobile technology is revolutionizing commerce and banking throughout the developing world, I couldn't leave the airport without first purchasing a mountain of worn rupees, their very fibers a preview of the dirt and sweat of the megalopolis. Cash may be inching toward obsolescence in wealthier countries, but in India and elsewhere

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BRIAN SMALE

the road to an all-digital economy is much longer. In order to do anything in Delhi—take a taxi, hire a translator, buy a bottle of water—I had to have cash, and plenty of it.

Perhaps I shouldn't have been surprised to learn that cash still has serious staying power. After all, it is deeply ingrained in our cultures. I'm not just talking about tipping strippers and under-the-table transactions. There is also Hanukkah gelt, offerings left at Buddhist shrines, showers of coins during Persian weddings, and suitcases stuffed with $100 bills in Hollywood heist movies. I have fond childhood memories of saving pennies to buy Bazooka bubble gum or lining them up on the Boston metro tracks, where my friends and I would watch the trains flatten them into shiny pancakes.

Still, I can't say I'll miss those jangly metal rounds and pale green slips of paper when they're finally gone. Now that I'm back to using them in my day-to-day life, they feel filthier and more antiquated than ever. Counting out change just to buy a cup of coffee reminds me that despite my mishaps trying to deal in anything but cash, the real challenge would have been to live a year dealing only in cash. Just imagine trying to pay your mortgage or your taxes with big wads of dough. Cash may still have footholds in some corners of society, but technological and monetary innovations are accelerating its demise. Will we be cashless in four years? Of course not. In 14? One can dream. ❏

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UNITED STATES OF AMERICA
HALF DOLLAR
LIBERTY
IN GOD WE TRUST
1971
LIBERTY
IN GOD WE TRUST
1977
UNITED STATES OF AMERICA
HALF DOLLAR
LIBERTY
IN GOD WE TRUST
1971

A Brief History of Money

Or, how we learned to stop worrying and embrace the abstraction

BY JAMES SUROWIECKI

IN THE 13TH CENTURY, THE CHINESE EMPEROR Kublai Khan embarked on a bold experiment. China at the time was divided into different regions, many of which issued their own coins, discouraging trade within the empire. So Kublai Khan decreed that henceforth money would take the form of paper.

It was not an entirely original idea. Earlier rulers had sanctioned paper money, but always alongside coins, which had been around for centuries. Kublai's daring notion was to make paper money (the *chao*) the dominant form of currency. And when the Italian merchant Marco Polo visited China not long after, he marveled at the spectacle of people exchanging their labor and goods for mere pieces of paper. It was as if value were being created out of thin air.

Kublai Khan was ahead of his time: He recognized that what matters about money is not what it looks like, or even what it's backed by, but whether people believe in it enough to use it. Today, that concept is the foundation of all modern monetary systems, which are built on nothing more than governments' support of and people's faith in them. Money is, in other words, a complete abstraction—one that we are all intimately familiar with but whose growing complexity defies our comprehension.

PHOTO: LEVI BROWN; PROP STYLIST: ARIANA SALVATO

THE FUTURE OF MONEY

The Evolution of Modern Money

Over the ages, money has become more abstract, virtual, and digital

3RD MILLENNIUM B.C.E.
Money is first mentioned in the written records of Mesopotamia.

7TH CENTURY B.C.E.
Lydia introduces the first standardized metal coins.

5TH CENTURY B.C.E.
The Greek city-state of Sparta bans gold coins as disruptive to warrior morale.

3RD CENTURY B.C.E
Roman Empire begins issuing coins.

5TH CENTURY C.E
With the fall of Rome, use of currency in the West declines.

FROM LEFT: TOMMASO DI GIROLAMO/GETTY IMAGES; NUMISMATIC GROUP; DE AGOSTINI/GETTY IMAGES(2)

Today, many people long for simpler times. It's a natural reaction to a world in which money is becoming not just more abstract but more digital and virtual as well, in which sophisticated computer algorithms execute microsecond market transactions with no human intervention at all, in which below-the-radar economies are springing up around their own alternative currencies, and in which global financial crises are brought on for reasons difficult to parse without a Ph.D. Back in the day, the thinking goes, money stood for something: Gold doubloons and cowrie shells had real value, and so they didn't need a government to stand behind them.

In fact, though, money has never been that simple. And while its uses and meanings have shifted and evolved throughout history, the fact that it is no longer anchored to any one substance is actually a good thing. Here's why.

LET'S START WITH WHAT MONEY is used for. Modern economists typically define it by the three roles it plays in an economy:

It's a *store of value*, meaning that money allows you to defer consumption until a later date.

It's a *unit of account*, meaning that it allows you to assign a value to different goods without having to compare them. So instead of saying that a Rolex watch is worth six cows, you can just say it (or the cows) cost $10 000.

And it's a *medium of exchange*—an easy and efficient way for you and me and others to trade goods and services with one another.

All of these roles have to do with buying and selling, and that's how the modern world thinks of money—so much so that it seems peculiar to conceive of money in any other way.

Yet in tribal and other "primitive" economies, money served a very different purpose—less a store of value or medium of exchange, much more a social lubricant. As the anthropologist David Graeber puts it in his recent book *Debt: The First 5000 Years* (Melville House, 2011), money in those societies was a way "to arrange marriages, establish the paternity of children, head off feuds, console mourners at funerals, seek forgiveness in the case of crimes, negotiate treaties, acquire followers." Money, then, was not for buying and selling stuff but for helping to define the structure of social relations.

How, then, did money become the basis of trade? By the time money makes its first appearance in written records, in Mesopotamia during the third millennium B.C.E., that society already had a sophisticated financial structure in place, and merchants were using silver as a standard of value to balance their accounts. But cash was still not widely used.

It's really in the seventh century B.C.E., when the small kingdom of Lydia introduced the world's first standardized metal coins, that you start to see money being used in a recognizable way. Located in what is now Turkey, Lydia sat on the cusp between the Mediterranean and the Near East, and commerce with foreign travelers was common. And that, it turns out, is just the kind of situation in which money is quite useful.

To understand why, imagine doing a trade in the absence of money—that is, through barter. (Let's leave aside the fact that no society has ever relied solely or even largely on barter; it's still an instructive concept.) The chief problem with barter is what economist William Stanley Jevons called the "double coincidence of wants." Say you have a bunch of bananas and would like a pair of shoes; it's not enough to find someone who has some shoes or someone who wants some bananas. To make the trade, you need to find someone who has shoes he's willing to trade *and* wants bananas. That's a tough task.

With a common currency, though, the task becomes easy: You just sell your bananas to someone in exchange for money, with which you then buy shoes from someone else. And if, as in Lydia, you have foreigners from whom you'd like to buy or to whom you'd like to sell, having a common medium of exchange is obviously valuable. That is, money is especially useful when dealing with people you don't know and may never see again.

The Lydian system's breakthrough was the standardized metal coin. Made

9TH CENTURY
The rise of feudalism in Europe further discourages the use of money and commerce.

12TH CENTURY
Trade revives in Europe; a banking system emerges in Italian city-states.

13TH CENTURY
Kublai Khan introduces paper money—the *chao*—as the chief currency throughout China.

15TH CENTURY
The bill of exchange is invented; traveling merchants can redeem it for gold in different cities.

16TH CENTURY
The amassing of silver and gold by Portugal and Spain triggers widespread inflation.

1690
The Massachusetts Bay Colony issues paper money to fund a military campaign.

1775
The American Continental Congress issues paper money but has too little gold to back it up.

FROM LEFT: UNIVERSAL IMAGES GROUP/GETTY IMAGES; HULTON ARCHIVE/GETTY IMAGES; WIKIPEDIA

of a gold-silver alloy called electrum, one coin was exactly like another—unlike, say, cattle. Also unlike cattle, the coins didn't age or die or otherwise change over time. And they were much easier to carry around. Other kingdoms followed Lydia's example, and coins became ubiquitous throughout the Mediterranean, with kingdoms stamping their insignia on the coins they minted. This had a dual effect: It facilitated the flow of trade, and it established the authority of the state.

Modern governments still like to place their stamp upon money, and not just on bills and coins. In general, they prefer that money—whether physical cash or digital—be issued and controlled only by official entities and that financial transactions (especially international ones) be traceable. And so the recent rise of an alternative currency like Bitcoin [see "The Cryptoanarchists' Answer to Cash," in this issue], which is based on a cryptographic code that allows for anonymous transactions and that so far has proved to be uncrackable, is the kind of thing that tends to make governments very unhappy.

THE SPREAD OF MONEY THROUGHOUT the Mediterranean didn't mean that it was universally used. Far from it. Most people were still subsistence farmers and existed largely outside the money economy.

But as money became more common, it encouraged the spread of markets. This, in fact, is one of the enduring lessons of history: Once even a small part of your economy is taken over by markets and money, they tend to colonize the rest of the economy, gradually forcing out barter, feudalism, and other economic arrangements. In part this is because money makes market transactions so much easier, and in part because using money seems to redefine what people value, pushing them to view things in economic, rather than social, terms.

Governments were quick to embrace hard currency because it facilitated the collection of taxes and the building of military forces. In the third century B.C.E., with the rise of Rome, money became an important tool for unifying and expanding the empire, reducing the costs of trade, and funding the armies that kept the emperors in power.

The decline of the Roman Empire, starting in the third century C.E., saw a decline in the use of money as well, at least in the West. Parts of the former empire, like Britain, simply stopped using coins. Elsewhere people still used money to balance accounts and keep track of debts, and many small kingdoms minted their own coins. But in general, the circulation of money became less central, as cities shrank in size and commerce dwindled.

The rise of feudal society also undercut money's role. The basic relationship between master and vassal was mediated not by payment for services rendered but rather by an oath of loyalty and a promise of support. Land was not bought and sold; it belonged, ultimately, to the king, who granted use of the land to his lords, who in turn provided plots of land to their vassals. And feudalism discouraged trade; a feudal estate, or fief, was often a closed community that aimed to be self-sufficient. In such a setting, money had little use.

Money's decline in feudal times is worth noting for what it reveals about money's essential nature. For one thing, money is impersonal. With it, you can cut a deal with, say, a guy named Jeff Bezos, whom you don't know and will probably never meet—and that's okay. As long as your money and his products are good, you two can do business. Similarly, money fosters a curious kind of equality: As long as you have sufficient cash, all doors are open to you. Finally, money seems to encourage people to value things solely in terms of their market value, to reduce their worth to a single number.

These characteristics make money invaluable to modern financial systems: They encourage trade and the division of labor, they reduce transaction costs—that is, the cost incurred in executing an economic exchange—and they make economies more efficient and productive. These same qualities, though, are why money tends to corrode traditional social orders, and why it is commonly

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1787
The U.S. Constitution bans the use of any money other than gold and silver.

1821
The Bank of England adopts the gold standard; most other countries follow suit.

1871
Western Union introduces money transfer service, allowing customers to wire money via telegraph.

1873–96
During the Long Depression, gold shortages trigger a worldwide economic recession.

1914–18
World War I derails the gold standard.

1921–24
Hyperinflation in Weimar Germany renders its paper currency worthless.

1930s
The Great Depression spells the end of the gold standard.

believed that when money enters the picture, economic relationships trump all other kinds.

It's unsurprising, then, that feudal lords had little use for the stuff. In their world, maintaining the social hierarchy was far more important than economic growth (or, for that matter, economic freedom or social mobility). The widespread use of money, with its impersonal transactions, its equalizing effect, and its calculated values, would have upended that order.

MONEY'S DECLINE DIDN'T LAST, of course. By the 12th century, even as the Chinese were experimenting with paper currency, Europeans began to embrace a new view of money: Instead of being something to hoard or spend, money became something to invest, to be put to work in order to make more money.

This idea came with a renewed interest in commerce. Trade fairs sprang up across Europe, frequented by a community of merchants who had begun to do business across the continent. This period also saw the emergence of a banking industry in the city-states of Italy. These new institutions introduced a host of financial innovations that we still use today, including municipal bonds and insurance. The banks fostered the use of credit and debt, which became ever more central to the economy as kings borrowed to finance their military adventures and merchants borrowed to fund their long-range trades.

The invention of the bill of exchange, which laid the groundwork for the emergence of paper money in the West, also occurred during this period. The bill of exchange was a sort of precursor to the traveler's check: a document representing a quantity of gold that could be exchanged for the real thing in a different city. Traveling merchants liked the bills because they could be carried around with far less risk (and exertion) than the precious metal.

By the 16th century in Europe, many of the ideas about money that shape our thinking today were in place. Still, money remained a physical thing—that thing being a piece of gold or silver. A gold coin wasn't a *symbol* of value; it was an *embodiment* of it, because everyone believed that the gold had intrinsic worth. Likewise, the amount of money in the economy was still a function of how much gold and silver was available. The rulers of Spain and Portugal didn't quite appreciate the limits of this system, however, which led them to plunder their New World colonies and accumulate vast hoards of precious metals, which in turn triggered periods of rampant inflation and enormous tumult in the European economy.

These days, countries have central banks to oversee their money supplies, as well as to set interest rates, combat inflation, and otherwise control their monetary policy. The United States has the Federal Reserve System, the Eurozone has the European Central Bank, the Maldives has the Maldives Monetary Authority, and so on. When the Federal Reserve wants to increase the money supply, it doesn't have to go looking for El Dorado. Neither does it phone up the United States Mint and order it to start printing more dollars; in fact, only about 10 percent of the U.S. money supply—about $1 trillion of the roughly $10 trillion total—exists in the form of paper cash and coins.

Instead, the Fed buys government securities, such as treasury bills, on the open market, typically from regular private banks, and then credits the banks' accounts with the money. As the banks lend, invest, and otherwise spend this new money, the overall money supply that's circulating increases. If, on the other hand, the Reserve wants to decrease the money supply, it does the opposite: It sells government bonds on the open market, again typically to private banks, and then deducts the sales price from the banks' accounts. The banks have less money to spend, and the money supply shrinks.

The sophisticated and relatively opaque machinations by which central banks keep economies afloat may make the Spanish Empire's inflationary foibles look quaintly naive. But in fact the fine-tuning of monetary policy—the delicate juggling of interest rates, money supply, and other financial

FROM LEFT: EVENING STANDARD/GETTY IMAGES; HULTON ARCHIVE/GETTY IMAGES; FRY DESIGN/GETTY IMAGES; GETTY IMAGES

1944
The Bretton Woods agreement sets up mechanisms for an international monetary system.

1950
The Diners Club issues the first modern credit card.

1995
Over 90 percent of transactions in the United States are made electronically.

1997
Finland's Merita Bank introduces the first mobile phone banking service, via SMS.

1999
The euro becomes the common currency of 11 European Union countries; 23 now use it.

2009
The cryptocurrency Bitcoin is unveiled.

2011
Facebook introduces its own currency: Facebook Credits.

mechanisms so that an economy keeps expanding at a steady, manageable rate, without excessive inflation, unemployment, debt, or boom and bust cycles—is still a work in progress, as the ongoing economic woes in both Europe and the United States demonstrate.

BACK TO THE 1600S: THE VIEW of money as commodity began to shift only with the widespread adoption of paper currency, which found the warmest welcome in the American colonies. In 1690, for instance, the Massachusetts Bay Colony issued paper money to fund a military campaign, and did so without explicitly promising to redeem the bills for gold or silver.

Later, during the American Revolutionary War, the Continental Congress printed "continentals" to pay for the new country's war debts. These bills were in principle backed by gold, but so many were issued that their collective value far exceeded the available gold. When soldiers and merchants discovered they'd been paid in near-worthless scrip, it inspired a backlash against paper money; the U.S. Constitution, for instance, prohibited states from using any other money than gold and silver coins. It wasn't until 1862, during the Civil War, that Congress finally passed a law allowing the government to print paper money, or "greenbacks."

That's not to say that paper money was unavailable before then. Even as the U.S. government minted nothing but coins, private banks, often called "wildcats," began issuing what in effect became thousands of currencies. Like the wartime continentals, these bank notes were in theory backed by gold, but it was hard to know whether a bank actually had enough gold to back up its notes, bank regulation being pretty much nonexistent at the time. Unsurprisingly, the wildcat era was fertile ground for fraud. What *is* surprising perhaps is that most banks did a reasonable job of keeping their currency and their gold reserves in balance, and the U.S. economy grew briskly.

The Bank of England, meanwhile, took a far more sober approach. In 1821, it adopted the gold standard, promising to redeem its notes for gold upon request. As other countries followed suit, the gold standard became the general rule for developed economies. The discovery of major new gold fields over the course of the 19th century ensured that the money supply kept growing.

The gold standard, as it was intended to do, brought stability to prices and was enormously beneficial to property holders and lenders. However, it also brought deflation—that is, prices generally fell—because as countries' populations and economies grew, their governments had no easy way to increase the money supply short of mining more gold, and so money in effect became more scarce. Deflation was hard on farmers and borrowers, who longed for a little inflation to help them with their debts; when money gradually loses some of its value, so, too, do people's debts.

The gold standard also didn't prevent economies from falling into recession, and when they did—as during the worldwide slump known as the Long Depression, which lasted from 1873 to 1896—adherence to the standard made it difficult to do any of the things that might have quickly set things right, like cutting interest rates or pumping more money into the economy. As a result, economies took a long time to recover from downturns.

Of course, clever financial minds will always find an end run around the rules. Having a gold standard, it turns out, didn't completely limit the growth of money. Banks could still make loans against their gold reserves, and they did so freely. Economic historians now believe that the amount of paper currency in circulation dwarfed the actual amount of gold and silver that banks had on hand. And so, while money was still tethered to gold in people's minds, it had already begun to become unhooked.

WHAT FINALLY DERAILED THE gold standard was World War I. Governments needed more money for their militaries than they had in gold, and so they simply began printing it. And though many countries tried to return to the gold standard after the

FROM LEFT: GEORGE SKADDING/TIME & LIFE PICTURES/GETTY IMAGES; SMITHSONIAN; ISTOCKPHOTO; CASASCIUS; JOE RAEDLE/GETTY IMAGES war, the Great Depression ended that experiment for good.

The result? Currencies today are "fiat" currencies, meaning they're backed by the authority of the issuing government, and nothing more. In the United States, for example, that means the government accepts only dollars as payment for taxes and requires its creditors to accept dollars in payment for debts. But if people were to lose faith in the dollar and stop accepting it in everyday transactions, it would eventually become worthless.

Many people find this situation unnerving, which is why there are perennial calls to return to the gold standard. The reliance on fiat money, we're told, gives too much power to the government, which can recklessly print as much money as it wants. Yet the truth is that this has always been possible. Even with the gold standard, governments revalued their currencies from time to time, in effect dictating a new price for gold, or they ignored the standard when it proved too limiting, as during the First World War.

What's more, the notion that gold is somehow more "real" than paper is, well, a mirage. Gold is valuable because we've collectively decided that it's valuable and that we'll accept goods and services in exchange for it. And that's no different, ultimately, from our collective decision that colorful rectangles of paper are valuable and that we'll accept goods and services in exchange for them.

The reality is that it's a good thing that we've moved away from the gold standard and the idea that money needs to be tied to something else. In the first place, it's honest: As soon as we left behind the habit of trading cattle for barley (both of which had intrinsic value), money became a social convention, and paper money just makes that convention obvious. These days, instead of worrying about where we're going to find more gold and silver, we can focus on how to wisely manage the money supply for the greater good.

Second, and more important, abandoning the gold standard has given central banks much more flexibility in dealing with economic downturns. Recessions are downward spirals: Instead of spending and investing, people and businesses hold on to their cash, which shrinks overall demand, which forces businesses to cut back, which creates unemployment, which shrinks demand even more.

One solution is for governments to make up the difference by spending more. But it's also important for interest rates to drop and for the money supply to increase, thereby making it easier for people to borrow money and helping overcome their reluctance to spend. Such actions are easier for the folks at the Federal Reserve and other central banks to pull off when they don't have to worry about maintaining the gold standard. And recessions have been shorter and less painful since the gold standard was abandoned. Even the most recent global downturn, severe as it was, was minor compared to the Great Depression.

Of course, all this talk of central bankers tinkering with the money supply is precisely what critics of the fiat money system dread, because they believe it will inevitably lead to runaway inflation. And history does show that when a government massively and carelessly expands the money supply, it ends up with hyperinflation and a worthless currency, as happened in Weimar Germany in 1923 and in Zimbabwe just a few years ago.

But such episodes are rare. In the past 90 years, the United States and Europe have had just one sustained bout of high inflation—in the 1970s. That track record should engender some faith; on the whole, central bankers act responsibly, and healthy industrial economies aren't prone to regular inflationary spirals. But that faith is apparently hard to muster; instead, it feels to many of us as if inflation is always about to soar out of control.

This irrational fear is ultimately a legacy of the way money evolved: We cling to the belief that money needs to be backed by something "solid." In that sense, we're just like Marco Polo—still a bit amazed by the thought that you can base an entire economy on little pieces of paper.

And yet we do. For more than 80 years, we've been living in a world in which money can be created, in effect, out of thin air. As we've already discussed, the central banks can create money, but so can ordinary banks. When a bank makes a loan, it typically just puts the money into the borrower's bank account, whether or not it has that money on hand—banks are allowed to lend more money than they have in their reserves. And so with each home equity loan, car loan, and mortgage, banks add incrementally to the money supply.

There is, to be sure, something a bit eerie about all this, and periods like the recent housing bubble, when banks made an extraordinary number of bad loans, should remind us of the dangers of runaway credit. But it's a mistake to yearn for a more "solid" foundation for the monetary system. Money is a social creation, just like language. It's a tool that can be used well or poorly, and it's preferable that we have more freedom to use that tool than less.

Over the course of history, the material substance of money has become less important, to the point that these days people talk easily about the possibility of a cashless society. The powerful combination of computers and telecommunications, of smartphones and social media, of cryptography and virtual economies, is what fuels such talk. And that progression makes sense because what matters most about money is not what it is, but what it does. Successful currencies, after all, are those that people use: They lubricate commerce, allow people to exchange goods and services, and thus encourage people to work and create. The German sociologist Georg Simmel described money as "pure interaction," and that description seems apt—when money is working as it should, it is not so much a thing as it is a process.

This, perhaps, is what Kublai Khan understood seven centuries ago. It's what we're still trying to understand today. ❑

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THE FUTURE OF MONEY

The Cryptoanarchists' Answer to Cash

How Bitcoin brought privacy to electronic transactions

BY MORGEN E. PECK

THERE'S NOTHING LIKE A DOLLAR BILL FOR paying a stripper. Anonymous, yet highly personal—wherever you use it, that dollar will fit the occasion. Purveyors of Internet smut, after years of hiding charges on credit cards, or just giving it away for free, recently found their own version of the dollar—a new digital currency called Bitcoin.

You'll know it when you see it (strippers who accept tips in bitcoins advertise their account addresses right on their bodies). And more important, if you pay with it, no one needs to know. Bitcoin balances can flow between accounts without a bank, credit card company, or any other central authority knowing who is paying whom. Instead, Bitcoin relies on a peer-to-peer network, and it doesn't care who you are or what you're buying.

In the long run, a system like this, which restores privacy to electronic payments, could do more than just put the sneak back into the peek. If enough people take part, Bitcoin or another system like it will give political dissidents a new way to collect donations and criminals a new way to launder their money—while causing headaches for traditional financial gatekeepers.

HARRY CAMPBELL

Virtual Currency Gets Real

Will Facebook Credits and other social scrip challenge government-backed currencies?

BY RACHEL COURTLAND

VIRTUAL CURRENCY IS WHAT YOU use to pay for a virtual tractor for your virtual farm or for a healing elixir for your avatar. But the market for digital scrip is expanding, leading some to speculate that virtual currencies will one day grow so large that they'll have a big effect on real-world economies. Opinions are split about whether that will be a good thing or a bad thing.

What's beyond dispute is the fact that business is booming. Revenues from the sale of virtual goods in online games and social networks is expected to rise to an estimated US $2.4 billion this year in the United States alone—up a good 40 percent over last year, according to researchers at Javelin Strategy & Research, based in Pleasanton, Calif. Some estimates suggest the global market could be 10 times as big.

One of the big drivers of this growth is Facebook, which now boasts more than 900 million users. Last year the social network mandated that Facebook games use its own currency—Facebook Credits—when accepting payments. So far, the currency's utility is limited. Facebook Credits can be purchased using dozens of currencies, but they can't easily be converted to cash. So, for example, you can use them to buy that virtual tractor in a Facebook game or rent a movie, but you can't send them to your friends as a gift or pay for something in a private transaction. And the app developers who receive Facebook Credits are charged a steep premium—Facebook skims 30 percent off each transaction, roughly 10 times as much as what credit card companies charge U.S. merchants.

But the emergence of Facebook Credits highlights a changing landscape. "Virtual currencies are no longer isolated play-money systems," says Edward Castronova, a professor of telecommunications and cognitive science at Indiana University, in Bloomington, who studies the

You may have heard about Bitcoin last year, when the digital currency was briefly a major media story and speculators rushed to cash in on the rising value of bitcoins. Or perhaps you heard about hackers raiding the coffers of the largest online bitcoin exchanges, which coincided with the price of bitcoins plunging. Since January Bitcoin has stabilized. It's been holding an exchange rate of about US $5.

The dream of an anonymous, independent digital currency—one where privacy is maintained for buyers and sellers—long predates Bitcoin. Despite obituaries in magazines like *Forbes*, *Wired*, and *The Atlantic*, the dream is far from dead.

THE PURSUIT OF AN independent digital currency really got started in 1992, when Timothy May, a retired Intel physicist, invited a group of friends over to his house outside Santa Cruz, Calif., to discuss privacy and the nascent Internet. In the prior decade, cryptographic tools, like Whitfield Diffie's public-key encryption and Phil Zimmermann's Pretty Good Privacy, had proven useful for controlling who could access digital messages. Fearing a sudden shift in power and information control, governments around the world had begun threatening to restrict access to such cryptographic protocols.

May and his guests looked forward to everything those governments feared. "Just as the technology of printing altered and reduced the power of medieval guilds and the social power structure, so too will cryptologic methods fundamentally alter the nature of corporations and of government interference in economic transactions," he said. By the end of the meeting, the group had given themselves a name—"cypherpunks"—and the superhero-like task of defending privacy across the digital world. In just a week, cofounder Eric Hughes wrote a program that could receive encrypted e-mails, scrub away all identifying marks, and send them back out to a list of subscribers. When you signed up, you got a message from Hughes:

Cypherpunks assume privacy is a good thing and wish there were more of it. Cypherpunks acknowledge that those who want privacy must create it for themselves and not expect governments, corporations, or other large, faceless organizations to grant them privacy out of beneficence.

Hughes and May were deeply aware that financial behavior communicates as much about you as words can—if not more. But outside of cash transactions or barter, there's no such thing as a private transaction. We rely on banks, credit card companies, and other intermediaries to keep our financial system running. Will those corporations save and even share a dossier of your spending habits? Even using cash requires trust that the bill will maintain its worth. Will governments print too much currency or too little? Many cypherpunks would say that the only way to answer these questions is to build an entirely new system.

Gradually, their mistrust germinated into an anarchist philosophy. Most simply wanted to be able to buy things without someone looking over their shoulders. But others on the mailing list imagined liberating currency from governmental control and then using it to lash back at their perceived oppressors.

Jim Bell, a onetime Intel engineer, took these fancies further than anyone, introducing the world to an odious thought experiment called an assassination market. Citizens needed an effective way to punish politicians who acted against the wishes of their constituents, he reasoned, and what better punishment than murder? With an anonymous digital coin, argued Bell, you could pool donations from disgruntled citizens into what amounts to economies of virtual worlds. "I think it's just a matter of time before Facebook Credits—or something like them—break free of cyberspace and have a big effect on the economy."

If virtual currency continues to grow, there may be some reason for concern, says Beth Robertson, Javelin's director of payments research. First, the international nature of virtual currency could make it fairly easy to launder money. Second, because they are privately managed, virtual-money systems could present an alternate route for trading sovereign currencies by exchanging, say, dollars for *World of Warcraft* Gold and then *World of Warcraft* Gold for yen. If an exchange rate is attractive enough, it could cause a flood of trading through a virtual venue, resulting in the rapid devaluation of a government-issued currency. "At the moment, virtual currencies aren't sufficiently big to destabilize any particular economy, but if [the industry] grows rapidly, it could have the potential to do that," Robertson says.

The growth of virtual currency has already driven some new regulation. In 2009, an explosion in the trade of prepaid cards for online services and the selling of gaming currency prompted China's Ministry of Culture and Ministry of Commerce to issue a rule banning the exchange of virtual currency for real goods and services.

But it's unclear how big virtual currency will get. One key limitation is trustworthiness. "Right now most companies treat virtual currency as something that you have a license to, and if your account is terminated, your license is terminated, and they don't have to pay you the value of it," says James Gatto, a partner at the law firm Pillsbury Winthrop Shaw Pittman. The question of ownership is still a new one for the courts. "There's just a whole host of unresolved legal issues that relate to this area," he says.

There is also the issue of utility. Unless a law is passed that transforms a virtual currency into legal tender, companies and individuals won't be obligated to accept it as a form of payment. The chances of such legislative changes occurring are slight, Gatto says: "I think virtual currency will continue to be used as it's currently used, at least for the foreseeable future."

But even if virtual currencies can never easily be used to pay for a cup of coffee or settle a debt, they still perform many of money's most common functions. And all signs suggest that their presence in our lives—as a convenient and relatively inexpensive way to make micropayments—will only grow. ❑

bounties. If a politician made enough people angry, it would only be a matter of time before the price pushed him out of office or cost him his life. Bell's essay, "Assassination Politics," eventually attracted the attention of federal agents. His spiral through the U.S. court system started with an IRS raid in 1997 and ended this March with his release from prison.

While cypherpunks like Bell were dreaming up potential uses for digital currencies, others were more focused on working out the technical problems. Wei Dai had just graduated from the University of Washington with a degree in computer science when he created b-money in 1998. "My motivation for b-money was to enable online economies that are purely voluntary," says Dai, "ones that couldn't be taxed or regulated through the threat of force." But b-money was a purely personal project, more conceptual than practical.

Around the same time, Nick Szabo, a computer scientist who now blogs about law and the history of money, was one of the first to imagine a new digital currency from the ground up. Although many consider his scheme, which he calls "bit gold," to be a precursor to Bitcoin, privacy was not foremost on his mind. His primary goal was to turn ones and zeros into something people valued. "I started thinking about the analogy between difficult-to-solve problems and the difficulty of mining gold," he says. If a puzzle took time and energy to solve, then it could be considered to have value, reasoned Szabo. The solution could then be given to someone as a digital coin.

In Szabo's bit gold scheme, a participant would dedicate computer power to solving cryptographic equations assigned by the system. "Anything that works well as a proof-of-work function, producing a specific binary string such that it can be proved that generating that string was computationally costly, will work," says Szabo. In a bit gold network, solved equations would be sent to the community, and if accepted, the work would be credited to the person who had done it. Each solution would become part of the next challenge, creating a growing chain of new property. This aspect of the system provided a clever way for the network to verify and time-stamp new coins, because unless a majority of the parties agreed to accept new solutions, they couldn't start on the next equation.

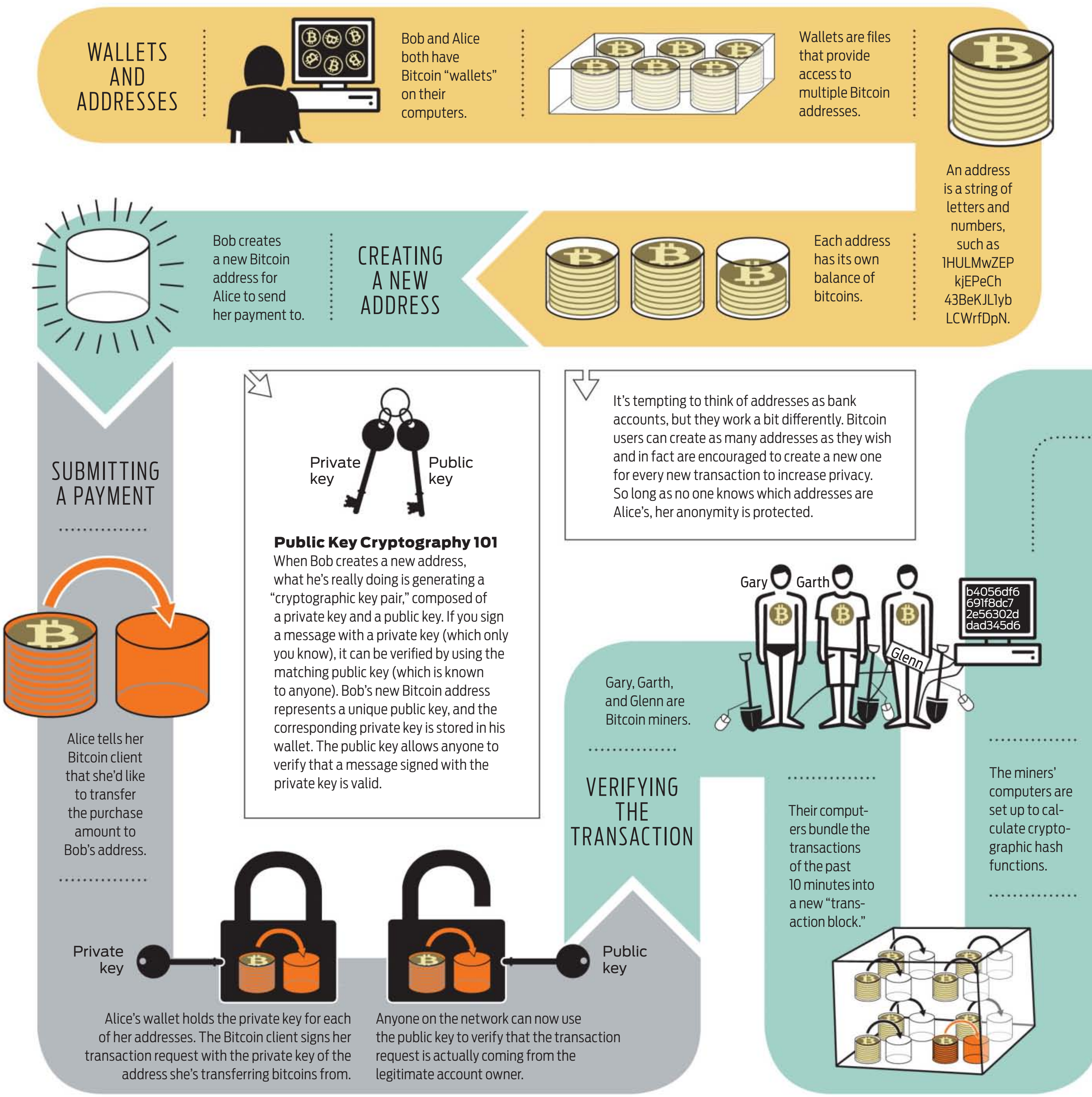
When attempting to design transactions with a digital coin, you run into the "double-spending problem." Once data have been created, reproducing them is a simple matter of copying and pasting. Most e-cash scenarios solve the problem by relinquishing some control to a central authority, which keeps track of each account's balance. DigiCash, an early form of digital money based on the pioneering cryptography of David Chaum, handed this oversight to banks. This was an unacceptable solution for Szabo. "I was trying to mimic as closely as possible in cyberspace the security and trust characteristics of gold, and chief among those is that it doesn't depend on a trusted central authority," he says.

Bit gold proved that it was possible to turn solutions to difficult computations into property in a decentralized fashion. But property is not quite cash, and the proposal left many problems unsolved. How do you assign proper value to different strings of data if they are not equally difficult to make? How do you encourage people to recognize this value and adopt the currency? And what system controls the transfer of currency between people?

AFTER B-MONEY AND bit gold failed to garner widespread support, the e-money scene got pretty quiet. And then, in 2008, along came a mysterious figure who wrote under the name "Satoshi

How a Bitcoin transaction works

Bob, an online merchant, decides to begin accepting bitcoins as payment. Alice, a buyer, has bitcoins and wants to purchase merchandise from Bob.



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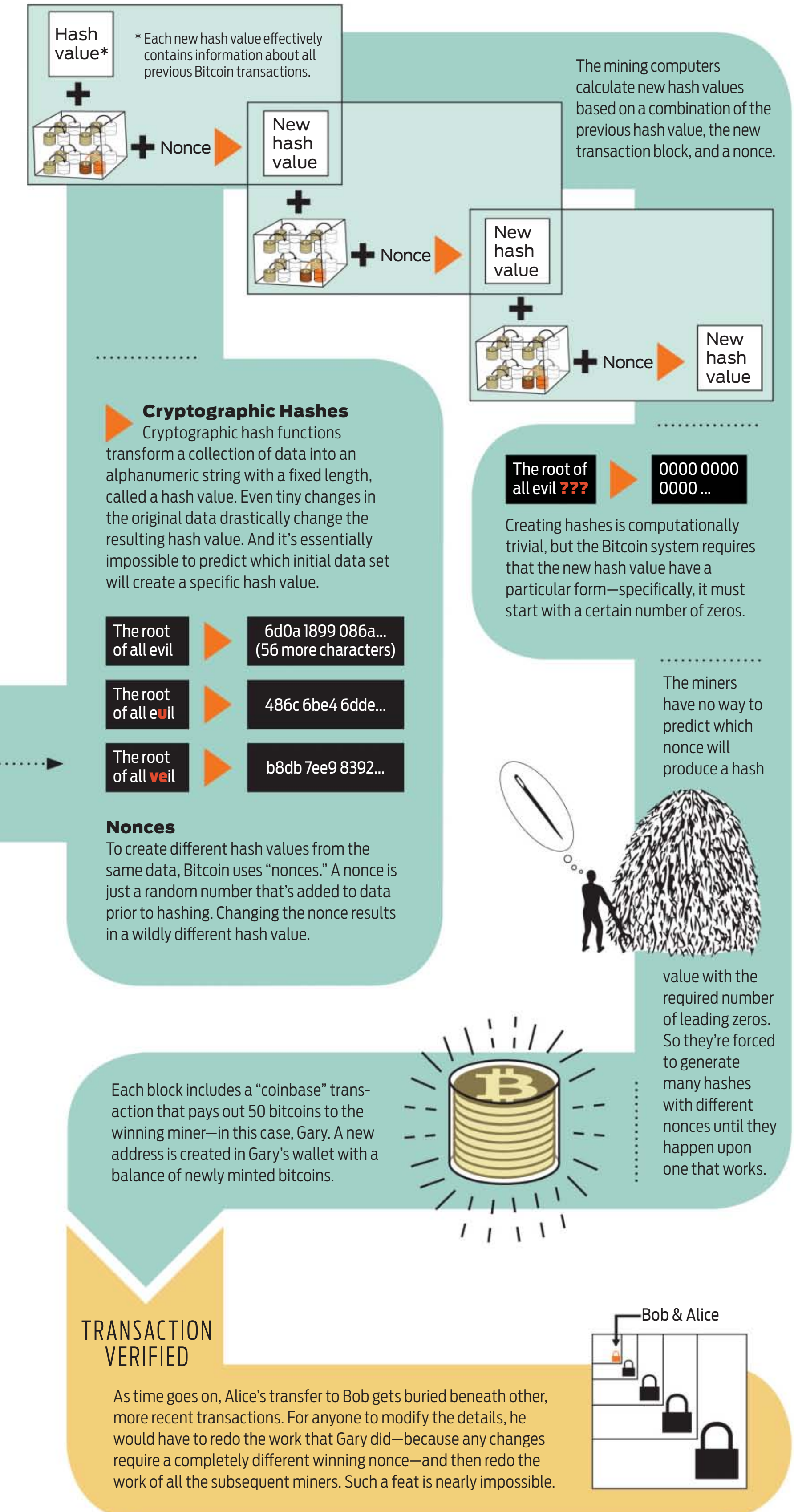

JOSHUA J. ROMERO; BRANDON PALACIO & KARLSSONWILKER INC.

Nakamoto," with a proposal for something called Bitcoin. As is fitting for the creator of a private digital currency, Nakamoto's true identity remains a secret. "I've never heard of anybody who knew about that name earlier," says Szabo. "And I'm not going to speculate on who he may or may not be."

To create a working system, Nakamoto started with the idea of a chain of data, similar to bit gold. But rather than creating a chain of digital property, Bitcoin records a chain of transactions.

The simplest way to understand Bitcoin is to think of it as a digital ledger book. Imagine a bunch of people at a table who all have real-time access to the same financial ledger on laptops in front of them. The ledger records how many bitcoins each person at the table has at a given time. By necessity, the balance of each account is public information, and if one person wants to transfer funds to the person sitting across from him, he has to announce that transaction to everyone at the table. The entire group then appends the transaction to the ledger, which they all need to agree on. In a system like this, money never has to exist in a physical form, and yet it can't be spent twice.

This is basically how Bitcoin works, except that the participants are spread across a global peer-to-peer network, and all transactions take place between addresses on the network rather than individuals. Address ownership is verified through public-key cryptography, without revealing who the owner is.

The system turns traditional banking privacy on its head: All transactions are made in public, but they're difficult to link up with a human identity. Maintaining the dissociation takes vigilance on the part of the Bitcoin user and careful decisions about which outside applications and exchange methods to use, but it can be done. "Anonymity is typically compromised by means outside of Bitcoin's control," says Jeff Garzik, who is on the

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team of programmers now responsible for developing the Bitcoin software. Bitcoin is often described as providing pseudoanonymity, by creating enough obfuscation to provide users with plausible deniability.

People who own bitcoins have a program—called the Bitcoin client—installed on their computers to manage their accounts. When they want to access their funds, they use the client to send a transaction request. The innovation of Bitcoin is to use the processing of these transaction requests as the mechanism for creating new currency.

As requests pile up in the system, individual computers, running "mining" programs, bundle them into chunks called transaction blocks. Before each block of transactions becomes part of the accepted Bitcoin ledger, or block chain, the mining software must transform the data using cryptographic hash equations. The Bitcoin client accepts the resulting hash values only if they meet strict criteria, so miners typically need to compute many hash values before stumbling upon one that meets the requirements. That process costs a lot of computing power—so much that it would be prohibitively difficult for anyone to come along and redo the work. Each new block that gets added and sealed strengthens all the previous blocks on the chain.

The "miner" whose computer first finds an acceptable hash value is rewarded with newly minted bitcoins. The Bitcoin system adjusts the difficulty of the hashing requirements to control the minting rate. To its proponents, this is one of Bitcoin's biggest attractions: Unlike the printing of "fiat" currency, which can be done on demand, the creation of Bitcoins will gradually taper until it reaches a limit of 21 million coins.

As more and more miners compete to process transactions, mining requires more computing power. Brock Tice, who mines bitcoins in St. Paul, Minn., has a whole room stuffed full of enough mining computers to heat his office in the winter. But Tice first became interested in the network for a different reason. He thought it would be a better way to accept money from customers online.

In 2009, he began selling little blue canary-shaped night-lights from his home. He quickly lost patience with all the standard payment options. "I had been thinking for a while that something like Bitcoin was needed," he says. "I run a couple of small businesses, and taking or making payments is just such a huge pain." Every time a customer pays with PayPal, for instance, Tice hands over 2.9 percent of what he charges plus a small fee. For international sales, he pays even more. The rates for Google Checkout and credit cards are about the same, and for each one he has to open an account with the company processing the transaction, and then trust that it will eventually hand over the money. After reading about how Bitcoin works, Tice decided to include it as a payment method on his website.

For merchants like Tice, the benefits are obvious. In addition to relieving him of fees (at least for now—Bitcoin has an optional mechanism in place for miners to collect fees in the future), Bitcoin transactions won't open him up to claims of credit card fraud. In Bitcoin, all transactions are irreversible.

On the other hand, unlike credit card users, consumers paying with bitcoins have no way to get their money back if Tice never ships the item. But as with any financial transaction, some level of trust is still required. And some customers would prefer to trust a merchant to make good on a sale than trust them to protect sensitive data. Last spring, hackers broke into the Sony PlayStation Network and swiped a trove of private account details—credit card numbers, birthdays, log-ins, passwords, home addresses, and all the names associated with them. Just days later, it happened again, and within a week the security of more than 100 million Sony accounts was at risk. "I think Bitcoin really has the potential to change our expectations about what information we give merchants," says Gavin Andresen, Bitcoin's project leader.

The Bitcoin system has had its own hacking problems. Other than a few die-hard miners, most people buy bitcoins at an exchange where you pay dollars, euros, or whatever and get bitcoins in return. These exchanges also allow merchants to convert their bitcoin collections into other currencies. Unfortunately, the security of the exchanges hasn't been as good as the Bitcoin client itself. The largest online exchange, Mt. Gox, lost 500 000 bitcoins to hackers in June 2011, which sent the price barreling down. Anyone who invests in a bitcoin better understand that it's going to be more volatile than the dollar, says Michael Kagan, the managing director at ClearBridge Advisors, an investment firm in New York City.

Even with the ups and downs, many of Bitcoin's early adopters amassed their virtual fortunes when mining was easy, so they have an incentive to keep the system going (assuming they didn't cash out at the peak of the bubble). It's possible they are hoarding the currency, as the economist Paul Krugman speculated they would, waiting for the price to rise again as mining becomes more competitive and expensive. And while Bitcoin's fixed minting rate helped attract its most fervent early adopters, it also made the barrier to entry much higher for people who want to join now. "If anything is the Achilles' heel of Bitcoin, that probably is it," Szabo says.

If Bitcoin does fail, it may die in an act of cannibalism. Nakamoto introduced the block chain, but cryptographers are now already working on improvements. The minting rate is only one of many things that could be tweaked. "Bitcoin is the first of a new breed," says Garzik. "People will learn from Bitcoin and build something better, or Bitcoin's critical mass will force it to evolve and learn from its own mistakes." ❑

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THE FUTURE OF MONEY

Quantum Cash and the End of Counterfeiting

Physicists say they can make money that can't be copied—at least in theory BY MICHAEL BROOKS

SINCE THE INVENTION of paper money, counterfeiters have churned out fake bills. Some of their handiwork, created with high-tech inks, papers, and printing presses, is so good that it's very difficult to distinguish from the real thing. National banks combat the counterfeiters with difficult-to-copy watermarks, holograms, and other sophisticated measures. But to give money the ultimate protection, some quantum physicists are turning to the weird quirks that govern nature's fundamental particles.

At the moment, the idea of "quantum money" is very much on the drawing board. That hasn't stopped researchers from pondering what encryption schemes they might apply for it, or from wondering how the technologies used to create quantum states could be shrunk down "to the point of fitting it in your wallet," says Scott Aaronson, an MIT computer scientist who works on quantum money. "This is science fiction, but it's science fiction that doesn't violate any of the known laws of physics."

The laws that govern subatomic particles differ dramatically from those governing everyday experience. The relevant quantum law here is the no-cloning theorem, which says it is impossible to copy a quantum particle's state exactly. That's because reproducing a particle's state involves making measurements—and the measurements change the particle's overall properties. In certain cases, where you already know something about the state in question, quantum mechanics does allow you to measure one attribute of a particle. But in doing so you've made it impossible to measure the particle's other attributes.

This rule implies that if you use money that is somehow linked to a quantum particle, you could, in principle, make it impossible to copy: It would be counterfeit-proof.

THE VISIONARY PHYSICIST STEPHEN Wiesner came up with the idea of quantum money in 1969. He suggested that banks somehow insert a hundred or so photons, the quantum particles of light, into each banknote. He didn't have any clear idea of how to do that, nor do physicists today, but never mind. It's still an intriguing notion, because the issuing bank could then create a kind of minuscule secret watermark by polarizing the photons in a special way.

To validate the note later, the bank would check just one attribute of each photon (for example, its vertical or horizontal polarization), leaving all other attributes unmeasured. The bank could then verify the note's authenticity by checking its records for how the photons were set originally for this particular bill, which the bank could look up using the bill's printed serial number.

Thanks to the no-cloning theorem, a counterfeiter couldn't measure all the attributes of each photon to produce a copy. Nor could he just measure the one attribute that mattered for each photon, because only the bank would know which attributes those were.

But beyond the daunting engineering challenge of storing photons, or any other quantum particles, there's another basic problem with this scheme: It's a private encryption. Only the issuing bank could validate the notes. "The ideal is quantum money that anyone can verify," Aaronson says—just the way every store clerk in the United States can hold a $20 bill up to the light to look for the embedded plastic strip.

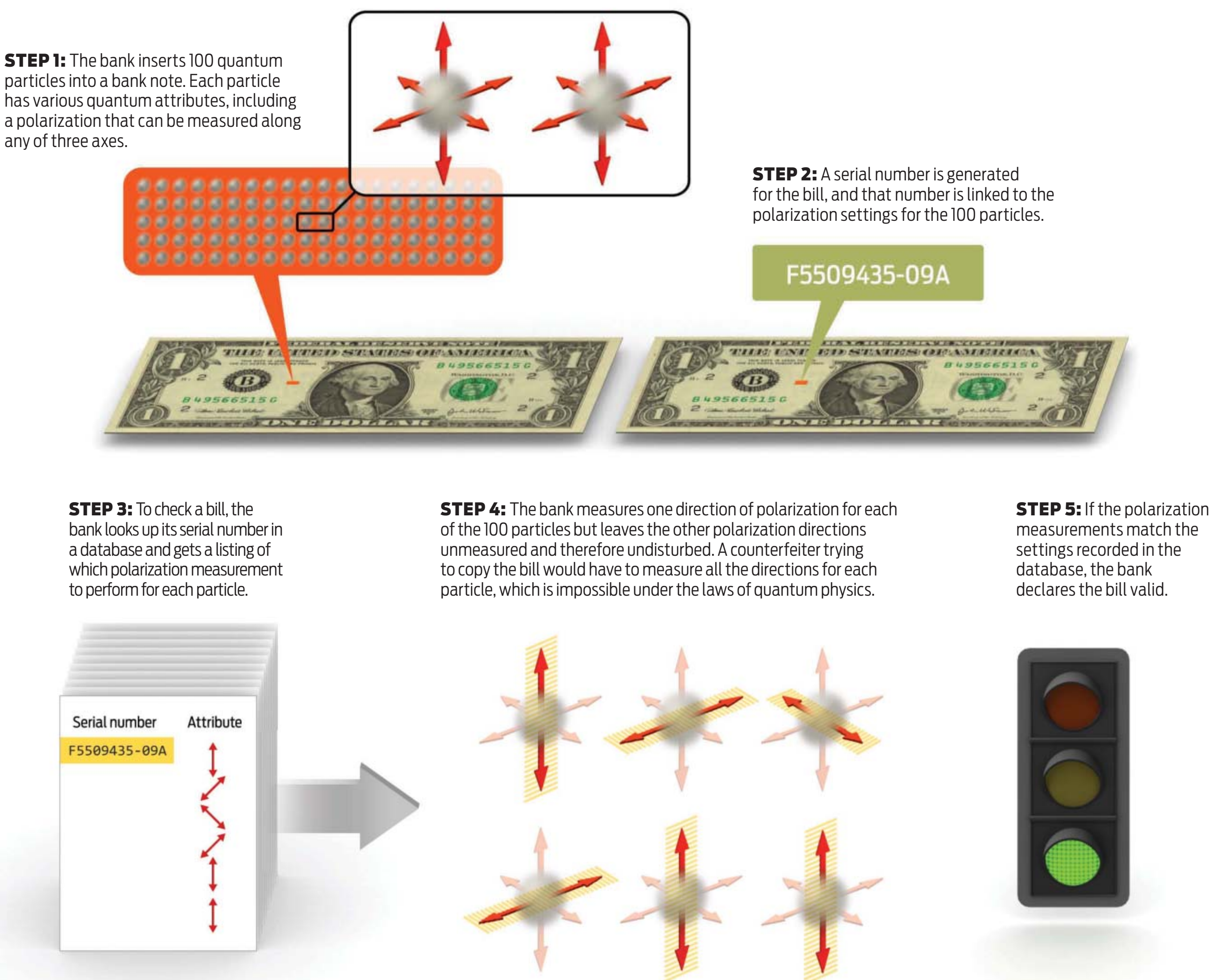
That would require some form of public encryption, and every such scheme researchers have created so far is potentially crackable. But it's still worth exploring how that might work. Verification between two people would involve some kind of "black box"—a machine that checks the status of a piece of quantum money and spits out only the answer "valid" or "invalid." Most of the proposed public-verification schemes are built on some sort of mathematical relationship between a bank note's quantum states and its serial number, so the verification machine would use an algorithm to check the math. This verifier, and the algorithm it follows, must be designed so that even if they were to fall into the hands of a counterfeiter, he couldn't use them to create fakes.

As fast as quantum money researchers have proposed encryption schemes, their colleagues have cracked them, but it's clear that everyone's having a great deal of fun. Most recently, Aaronson and his MIT collaborator Paul Christiano put forth a proposal in which each banknote's serial number is linked to a large number of quantum particles, which are bound together using a quantum trick known as entanglement.

ALL OF THIS IS PIE IN THE SKY, OF course, until engineers can create physical systems capable of retaining quantum states within money—and that will perhaps be the biggest challenge of all. Running a quantum economy would require people to hold information encoded in the polarization of photons or the spin of electrons, say, for as long as they required cash to sit in their pockets. But quantum states are notoriously fragile: They "decohere" and lose their quantum properties after frustratingly short intervals of time. "You'd have to prevent it from decohering in your wallet," Aaronson says.

For many researchers, that makes quantum money even more remote than useful quantum computers. "At present, it's hard to imagine having practical quantum money before having a large-scale quantum computer," says Michele Mosca of the Institute for Quantum Computing at the University of Waterloo, in Canada. And these superfast computers must also overcome the decoherence problem before they become feasible.

If engineers ever do succeed in building practical quantum computers—ones that can send information through fiber-optic networks in the form of encoded photons—quantum money might really have its day. On this quantum Internet, financial transactions would not only be secure, they would be so ephemeral that once the photons had been measured, there would be no trace of their existence. In today's age of digital cash, we have already relieved ourselves of the age-old burden of carrying around heavy metal coins or even wads of banknotes. With quantum money, our pockets and purses might finally be truly empty. ❑



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Phone-y Money

Why marketers are cramming digital wallets down our throats

BY PHILIP E. ROSS

IN TIMES GONE BY, WHEN YOU SUDDENLY REALIZED you were missing something—that you were effectively *naked*—the thing you were likely missing was your wallet. No longer.

"People can go for a whole day without their wallet and not freak out," says Bill Maurer, an anthropologist at the University of California, Irvine. "But if they're missing their smartphone, it's another story."

That's why marketers are now trying to hit you where it really counts—in your phone, or rather, a phone that will serve as your wallet. To that end, Google launched Google Wallet last year, collaborating with Sprint and Citi MasterCard. Google spent untold millions to subsidize the terminals that are increasingly to be found at checkout counters around the United States—terminals that can register the tap of a phone equipped with Near Field Communication (NFC).

It's also what Verizon, T-Mobile, AT&T, and their partners plan to do this summer, when they begin to roll out their rival service, Isis Mobile Wallet. Around the world similar programs, notably Orange's Quick Tap in Britain, are being unveiled.

HARRY CAMPBELL

In every case, what's involved are coalitions of financial, wireless, and Internet players, each of which has its own reason for wanting a piece of your business. "The credit card companies take their cut, the terminal companies get to sell more terminals, and the Internet company—say, Google, for Google Wallet—in the long run would be gathering lots of valuable information on customers," says Aravindh Vanchesan, a retailing and digital money analyst for the consultancy Frost & Sullivan. All the players will use that information, of course, to target ads to those customers.

These schemes have a lot of moving parts, Vanchesan notes, and right now he's betting on Isis to beat mighty Google, because Isis has signed on the three biggest wireless carriers in North America. Google Wallet's Sprint, by contrast, is the little fish in that pond.

But the most important moving part is the user, who may well ask, "What's in it for me?" And at least for the two big schemes under way in the United States, the answer is: not much. It'll take a fraction of a second less to buy something with a wave of your smartphone than with a swipe of your credit card, and it'll be easier for retailers to e-mail promotions. That's supposed to be a good thing.

Then again, with upsides like that, who needs downsides?

The pioneer of this form of marketing is Groupon, with its downloadable discount coupons. Its success appears to be what Google Wallet and Isis are trying to re-create and improve upon. The idea is to make promotions a much bigger part of a marketing strategy by hitting you when you're most susceptible to persuasion—at the very moment you're deciding whether, or what, to buy.

It's the dream of every member of the value chain—except the consumer. "A lot of the work is just treating the phone as a form factor—another shape of credit card," says Maurer, the anthropologist of money. "It doesn't use the smartphone's functionality." In Kenya, he notes, people use simple cellphones to text-message money to one another [see "Let a Thousand Currencies Bloom," in this issue]. Of course, in such emerging markets many users lack easy access to banks and credit cards, and they typically buy wireless service by the minute. But it might work even in Britain, where the telecom and Internet provider O_2 has just announced an app that allows any phone with an Internet browser to message up to £500 to any other phone with the app.

No such scheme has been broached in the United States, where nobody seems terribly enthusiastic about Google Wallet or the upcoming Isis. Indeed, the two services are vying for the title of Least Communicative Communications Service. A spokesman for Google Wallet promised to call *IEEE Spectrum*; we're still waiting. A spokesman for Isis offered to answer e-mailed questions but demurred after seeing them.

MILESTONE IN MONEY

1997: In Helsinki, a mobile phone is used for the first time to buy something: a soda from a Coca-Cola vending machine

Google's reticence, at least, is probably attributable to difficulties with the business and to a lesser extent the technical rollout, according to analysts familiar with the situation. Rick Oglesby, who works in the Phoenix office of Boston's Aite Group, says Google is rethinking its strategy of simply emulating credit cards on a smartphone. Google had favored this emulation scheme because it allows the company to avoid having to negotiate terms with each of the thousands of retailers out there who are already comfortable with credit cards.

Google may or may not have agreed to share revenue with Sprint, its wireless partner in this venture; neither one of them is saying. In any case, Google certainly has had to jump-start the manufacturing of Android phones that include the necessary chips for Near Field Communication, or NFC. The company has also fronted much of the cost of installing hundreds of the MasterCard Paypass terminals that read the NFC signals emanating from those chips. Oglesby says Google might instead store buy-and-sell information on a server that user and merchant can access through the mobile Web, thus circumventing the credit card companies' in-house networks.

In the end, Google wants to take a cut on the redemption of coupons and other offers that Google Wallet would deliver to the customer, much as the search company now takes a cut from click-throughs on its online ads. With this scheme, Google would get a fee every time it steered someone to buy something in a brick-and-mortar store.

Isis, Oglesby points out, is different: Because it's a creature of the big wireless carriers, it has good reason to stick with credit card emulation. "Their model is to manufacture phones with these secure [NFC] chips inside, in such a way that they own that chip," he says. "They are thus providing access to that chip for a fee."

So, is anybody at all trying to dream up services that will appeal to the consumer? Well, there's Square, in San Francisco, which is making a little dongle that turns a smartphone into a credit card swiper. Basically, Square is of interest to people who are paid frequently for relatively small products or services—say, for produce at a farmer's market, or landscaping, or child care. It also makes it easier for a fundraiser to corner a prospective donor for a handout at an event. "If they say, sure, they'll send a check later, I can pull out my phone and say, 'Why not just swipe

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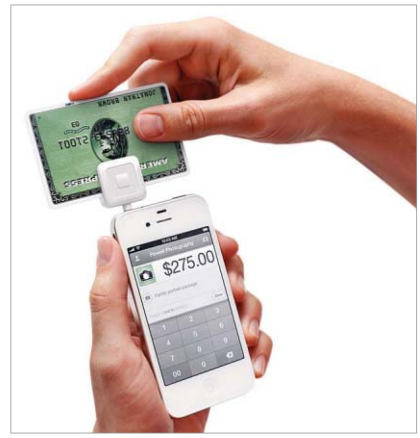

PHONE BANK: Google Wallet turns phones into cards [left]; Square [top] and PayPal [bottom] turn them into readers. But what people want are phones that can send money to any other phone.

PHOTOS: CLOCKWISE FROM LEFT: DAI SUGANO/SAN JOSE MERCURY NEWS/LANDOV; SQUARE; KIM WHITE/BLOOMBERG/GETTY IMAGES

your credit card right now?' " explains Shaun Smith, a manager at Chess in the Schools, a nonprofit based in New York City. And there's the past master of virtual payment, PayPal, about to launch its Digital Wallet, which will allow two users to transfer funds by tapping phones and let anyone juggle money in ways that once would have required a sit-down with a banker.

There's no reason why Google Wallet and Isis can't also find ways to please consumers while enriching themselves and their partners. And maybe they will, once they've built up their businesses enough to generate network effects of scale.

Look at the history of the credit card. Like the digital wallet, it began as a marketing ploy, a way for oil companies to instill loyalty in motorists in the United States in the 1920s. Next came general-purpose credit cards for businessmen on expense accounts. Finally, those cards shouldered aside travelers' checks. But the transition took a lifetime to accomplish, and we're talking about credit cards, which were obviously useful from the get-go. Digital wallets as they are presently constituted are not. What's needed is someone to reimagine things from the user's point of view, the way Google did exactly once in its history, when it ranked websites by popularity and placed relevant ads in parallel, but at a discreet distance.

This time around, Google seems to be looking at everything from one point of view only: its own. ❑

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THE FUTURE OF MONEY

No More Waiting on Near Field Communication

Start-ups are making mobile payments work without dedicated hardware

BY JOSHUA J. ROMERO

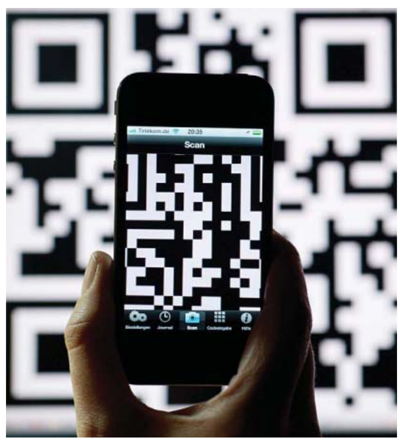
FOR YEARS, WHEN analysts and engineers talked about phones replacing our wallets, they focused on a single technology: Near Field Communication. NFC allows devices located within a centimeter or two of each other to establish a wireless connection.

But eight years after Nokia, Philips, and Sony founded the NFC Forum, the technology still isn't common in phones. In the United States, only two models, available on the Sprint network, have shipped with the NFC hardware to support Google Wallet. (Verizon Wireless's Galaxy Nexus phone has an NFC chip, but the company blocked its use for Google Wallet.) Certainly, there will be more NFC-enabled phones to choose from in the future: Over 100 models have been announced for 2012, according to analysts at the Swedish firm Berg Insight, more than twice as many as the 40 models released globally in 2011.

But just producing more NFC-enabled phones isn't enough. Stores still need to add NFC readers to all of their cash registers, and retailers don't want to spend money on that until there's significant demand. It's a classic chicken-and-egg situation.

In the meantime, mobile-payment start-ups aren't waiting around for NFC. They've found that most cellphones already have technologies available to make purchases work.

QR CODES Remember when there was a whole category of mobiles called camera phones? Today, a built-in camera is a standard feature, which means that most phones are capable of scanning Quick Response (QR) Codes, those square-shaped bar codes often seen on promotional posters. Numerous companies like DigiMo, LevelUp, and mFoundry have built payment schemes around QR scanning.



DigiMo's system uses the phone as a scanner—merchants post a QR code sticker at each register, which customers use their phones to scan. After the customer authenticates the purchase, the clerk completes the transaction by swiping a DigiMo-issued card through the store's existing mag-stripe system.

But QR codes can also be used in reverse. In schemes used by LevelUp and Starbucks (which uses mFoundry's technology), a customer displays a unique QR code on the phone, and the cashier scans it at the point of sale, allowing the equipment there to process the transaction.

ACCELEROMETERS Silicon Valley start-up Bump Technologies recently announced Bump Pay, which cleverly uses accelerometers and geolocation to let users exchange money between phones. To transfer money to a friend who also has the Bump Pay app, you just enter the amount, then bump the two phones together.

Bump Pay's system uses geolocation data to limit the search to nearby phones. Next, it compares the timing of accelerometer events to match up two phones that recorded an impact at the same time. Finally, it executes the transaction via PayPal.

Compared with NFC, it's an extremely convoluted solution for proximity sensing. But Bump shows how the nature of the problem has shifted. NFC was originally envisioned as an extension of smart-chip technology, where account balance information is stored in the device itself and transactions can be processed without connecting to the network. But in today's age of nearly constant data connectivity and cheap cloud processing, that's no longer necessary.

SMS In countries where most people have basic mobile phones, SMS-based payment schemes are popular. Essentially, these allow you to "text-message" money to anyone with a phone. The simplicity of SMS has made it easy for many mobile-payment start-ups to experiment. In 2010, Indian researchers found that across the globe SMS was being used to provide nearly every mobile financial service.

PayPal, now owned by eBay, was built on the ability to send funds between e-mail addresses. Now it has linked mobile phone numbers to e-mail accounts, and users can send payment via text message.

So is it too late for NFC? Not necessarily. But these alternatives may further slow adoption. NFC chips are good for a lot more than just mobile payments—opening digital locks, pairing wireless devices, or transferring data. But NFC proponents have long counted on mobile payments to be their killer app. Maybe it's time to reconsider. ❑

PATRICK PLEUL/DPA/LANDOV

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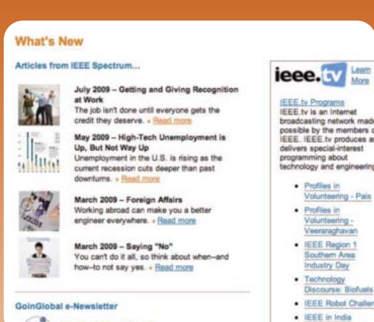

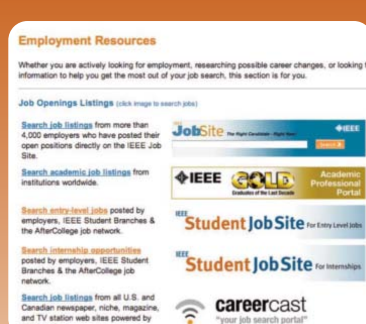

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The Microsecond Market

High-frequency trading has supercharged the financial industry, for better or worse

BY DAVID SCHNEIDER

SINCE MONEY FIRST CAME INTO EXISTENCE, SOME people have made gobs of it by having particularly timely access to important news. Perhaps the most notorious examples of this phenomenon took place during the first half of the last century in many U.S. cities. Here it was organized crime that profited immensely, and the news of interest was about horse races.

Initially, horse-race results were sent out over Western Union's telegraph network, but when that company cut off this service to what it deemed shady customers, others with fewer scruples stepped in. On their private wires, race results were sent from the tracks to illegal bookmakers before the public at large learned of them, allowing bookies to accept bets on horses that had already lost and turn down wagers on horses that had already won.

For decades, bookmakers paid handsomely for those wire services, helping to support such notable Chicago mobsters as Mont Tennes and Al Capone. Access to a fast wire carrying breaking results from the track was an offer that bookies couldn't refuse. A 1951 report of the United States Senate Special Committee to Investigate Crime in Interstate Commerce aptly notes, "The wire service is as essential to a book-maker as the stock ticker to a stockbroker."

PHOTO: LEVI BROWN; PROP STYLIST: ARIANA SALVATO

In today's age of live sports broadcasts, bookmakers can no longer profit this way. But big financial companies that buy and sell stocks and other financial instruments with automated split-second transactions can—and do. The companies engaged in this relatively new practice, called high-frequency trading, are keenly aware of the importance of timely information about markets. And they use enormously sophisticated technology to wring out every last bit of delay—down to the microsecond level or even less—in getting that information and in executing their trades.

A few years ago, hundreds of millions of dollars were spent on a project to connect traders in New York and Chicago with an especially direct data link, and similar amounts are being invested now to hook up New York and London in the fastest possible way. These are just of couple of the most obvious investments in a multibillion-dollar game where advantages measured in millionths of a second can mean millions in profits.

"In the age of high-frequency trading, technological speed itself is a strategy," says Benjamin Van Vliet, who teaches quantitative finance at the Illinois Institute of Technology's Stuart School of Business. He likens high-frequency trading to picking up gold coins dropped on the ground—not much analysis or insight is required. Speed, however, is. "Whoever is fastest is going to win every time," he says.

THE BUYING AND selling of stocks, commodity-futures contracts, and other financial instruments was traditionally a noisy affair, done by people calling out trades they wanted to make in the "pits" of various exchanges. Some of that still goes on, but most trading these days is done through the financial industry's various electronic communication networks. These first sprouted up in the late 1960s and bloomed in the decades that followed. But until fairly recently, people largely remained in the loop, watching how market conditions were changing on their computer screens and pointing and clicking to execute their trades.

Increasingly, though, more sophisticated market participants have been using preprogrammed strategies to execute their trades, often splitting up their purchase or sales orders and submitting them at odd times so that nobody else can easily discern their overall intentions. That strategy helps to avoid driving up the price while you're buying a lot of something or depressing it when you're selling.

But such "algorithmic trading" is less useful lately, because the automated platforms that high-frequency traders have put in place over the last few years react so swiftly. "Whenever I wanted to trade some stocks, it seemed someone was looking over my shoulder," says X. Frank Zhang of the Yale School of Management, who managed a US $500 million investment portfolio on Wall Street between 2008 and 2010 before taking his current academic post. "High-frequency traders could detect my patterns."

These traders were taking information about what orders were in play in the market and using it to predict how prices would most likely shift. Armed with that knowledge, they would buy and sell stocks or other instruments and sell them again within minutes or even seconds, most likely accruing only a tiny amount on each share traded. But the tiny profits can quickly add up, given the enormous number of transactions. People like Zhang, on the other hand, have to manage long-term investment portfolios. So even if they studied the high-frequency traders' patterns and strategies, it wouldn't help them do their jobs.

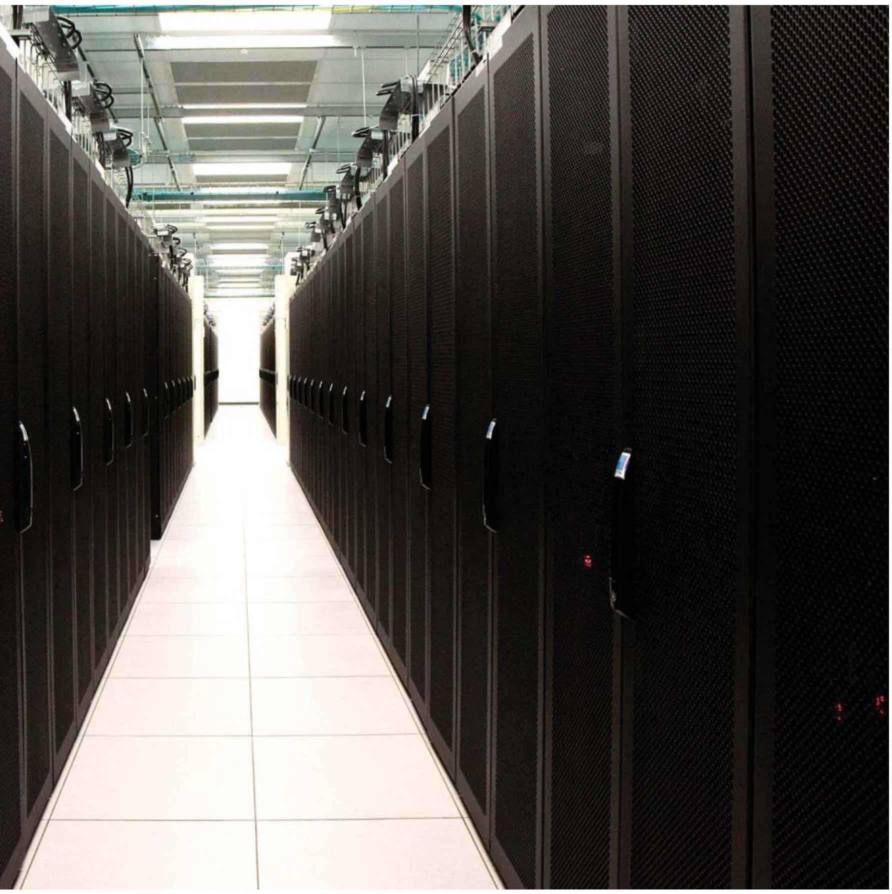
A study of U.S. financial markets that Zhang conducted in 2010 showed that high-frequency trading was responsible for 78 percent of the dollar trading volume in 2009, up from near zero in 1995. Other estimates are somewhat lower, but most are still well

MATCHING ENGINES: The New York Stock Exchange's data center in Mahwah, N.J., houses the exchange's many servers, along with the equipment of high-frequency trading firms that colocate there.

PHOTO: NYSE EURONEXT

over 50 percent. Not surprisingly, the value of high-frequency trading to the overall economy is controversial. Those engaged in the practice argue that, like the exchanges' "official market makers," they provide a valuable source of liquidity: With market makers buying and selling (as the official ones are contractually obligated to do, albeit at slightly different prices so that they can profit from their trades), there's always somebody to trade with when you want to exchange some stock.

Zhang, for one, is skeptical. He points out that unlike official market makers, high-frequency traders can



withdraw from the market at their discretion. As an example of the kind of problem that can cause, he cites the "Flash Crash" of 6 May 2010, when the Dow Jones average mysteriously fell by about 1000 points, only to recover minutes later. That crash has been blamed, in part, on the sudden disappearance of high-frequency trading when the market became unpredictable.

Zhang also says that the volume of high-frequency trading is too large to be justified in terms of providing liquidity to others. If every single traditional market participant bought from or sold to only high-frequency traders, he explains, they would account for only 50 percent of the trading volume. That's because the calculation of trading volume includes both purchases and sales. So with every transaction between a traditional investor and a high-frequency trader, each contributes the same amount to overall trading volume. That high-frequency traders are responsible for more than 70 percent of overall trading volume means that these firms must often be trading with one another.

THE NEW YORK STOCK EXCHANGE, at 11 Wall Street in lower Manhattan, might seem the epicenter of U.S. stock trading. In fact, the real action takes place about 50 kilometers away, in a huge, windowless building in suburban Mahwah, N.J. NYSE Euronext opened a 400 000-square-foot (37 000-square-meter) data center there in 2010. This is where the New York Stock Exchange houses its "matching engines"—servers that link together a vast number of buy and sell orders coming in from traders. It's also where the exchange leases space to companies that want their computerized trading equipment installed as close as possible to these matching engines so as to limit signaling delays, both in receiving market information and in executing trades. Every day, some $70 billion changes hands there electronically, with about 1.6 billion shares (out of a total of 6.8 billion in the United States) being bought and sold inside this one stock exchange's machines.

This data center is thus a key hub for U.S. financial markets. No wonder it's protected by armed guards, hydraulically operated steel barriers, and bomb-sniffing dogs. The high-frequency trading firms that colocate their equipment there enjoy a valuable speed advantage over others that are not so strategically placed. Some of those tenants had even hoped to garner a fraction of a microsecond's edge by positioning their equipment especially close to the exchange's matching engines. But that's impossible, by design.

"Everyone routes through the same set of switches, the same core network, the same local area network, and then [the data] is delivered at the same speed to each colocation customer's top of rack, wherever they are located—no one has an advantage," says Don Brook, global head of infrastructure for the NYSE. "The last piece of secret sauce to make that happen isn't really that secret: Every cable is the same length, whether you are 10 feet away or 500 feet away."

Although it seems rather wasteful to have kilometers of fiber-optic networking cable looping around in circles above the server racks, fairness (and the U.S. Securities and Exchange Commission) demand such attention to detail in leveling the playing field among the exchange's colocated customers. That doesn't mean, though, that mere chance determines which of those customers will be quickest to grab those gold coins off the ground (to use Van Vliet's analogy). Technology

TOWER POWER: Microwave relays may soon be the fastest way for traders to signal between New York and Chicago.
PHOTO: JIM SULLIVAN/MCKAY BROTHERS

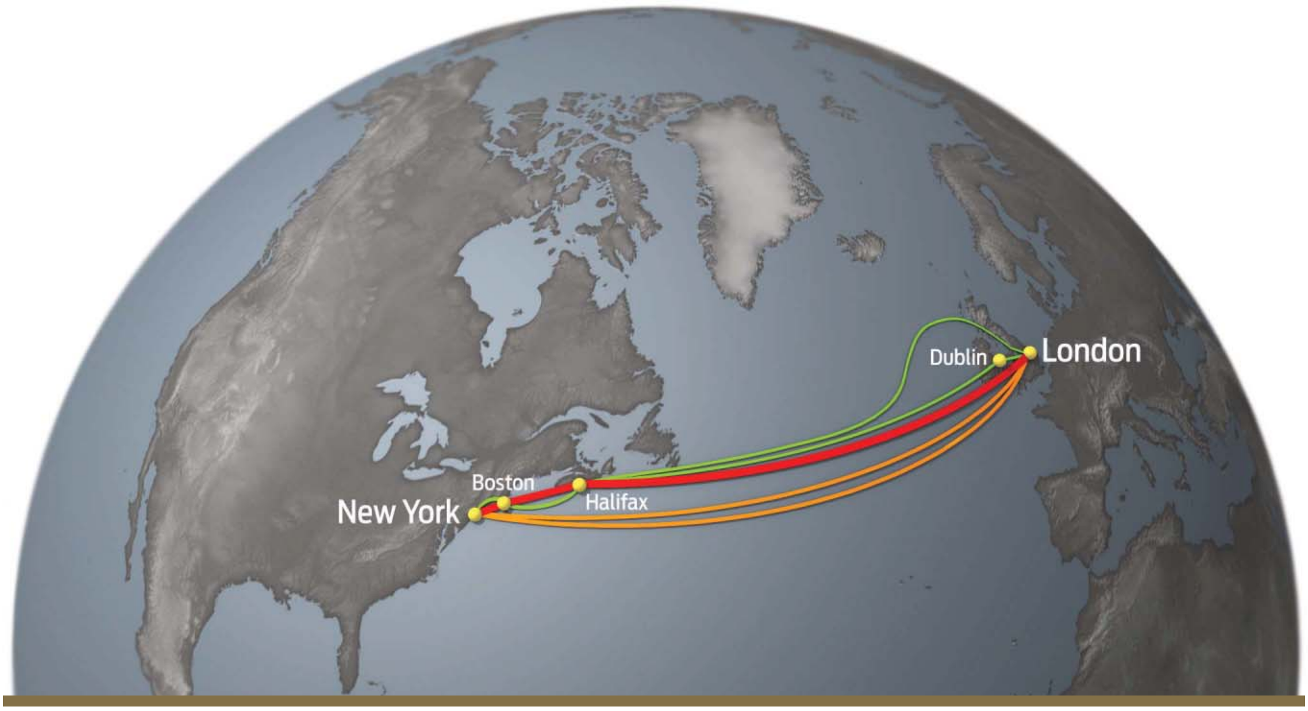
determines that. "Customers do everything they can to reduce latency inside their boxes," says Brook.

One of the companies they turn to for help in that race is Solace Systems of Ottawa, Canada. A hardware-based networking appliance that Solace sells is used to connect high-frequency traders' servers with special-purpose "feed handlers," which format the raw data feeds that such exchanges provide. "You can use software for this," says Shawn McAllister, chief technology officer of Solace Systems. "That's traditionally done, but it's slower." And that makes Solace's ultrafast hardware an easy sell.

The microseconds you save by going to such extremes are well worth the effort, because high-frequency traders often seek to profit using a relatively simple strategy: examining the current set of orders and predicting how prices will shift in response in the next instant. Designing algorithms to make such predictions isn't all that challenging, and running the code needed to carry them out isn't all that computationally taxing—what's hard is coming up with those predictions and acting on them faster than anyone else can.

Another general strategy that high-frequency traders use is arbitrage. The basic idea behind arbitrage is that the prices of certain financial instruments are fundamentally linked. So if you find two things that ought to have the same value but are temporarily showing different prices, you should buy the cheaper one, or borrow and then sell the more expensive one. You'll make a profit if the price of the cheaper one rises or the price of the more expensive one declines. Because it's hard to know which will happen (or if the price of both will shift together because of other factors), the best strategy is to buy and sell the two things simultaneously. You'll then profit in any event.

A concrete example here helps. Chicago has long been a hub for trading in futures contracts, which are agreements that give you the right to



Speedy Crossing Hibernia Atlantic's Project Express, a fiber-optic cable to be laid in 2013 [route shown in red], will shave a couple of milliseconds off the time it takes to send a signal between New York and London. High-frequency traders are signing up now.

buy or sell something—corn or pork bellies, say—for a given price at some date in the future. On some Chicago exchanges, you can also buy and sell futures contracts on the stock of companies—often companies being traded on the New York Stock Exchange. The prices of those futures contracts are, of course, closely linked to the prices of the underlying stocks.

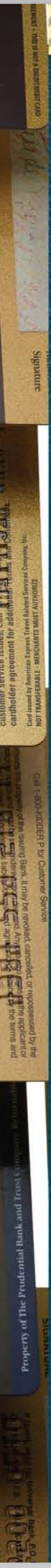
Now suppose the price of such a stock changes in New York—or rather, inside the servers in Mahwah, N.J. You can be pretty sure that the price of related futures contracts will shift accordingly in Chicago. But that won't happen instantaneously: It will take 7 milliseconds or more for a report of the stock's price change to reach Chicago through the fiber-optic cables linking these two financial centers. If you got wind of the news faster than that, your lightning-fast computerized trading machines could use "latency arbitrage" to profit. The TABB Group estimates that $21 billion is made with latency arbitrage every year. No wonder considerable engineering effort has gone into finding ways to transmit such news as fast as is technically possible.

ILLUSTRATION: EMILY COOPER

IN JUNE 2010, SPREAD Networks, of Ridgeland, Miss., announced that it had installed a fiber-optic communications cable between New York and Chicago that followed an especially direct route. That required blasting though mountains at a cost of perhaps several hundred million dollars. Lease bandwidth on that line, the company suggested to high-frequency traders, and you'll shave more than a millisecond off the time it takes you to send information between the two cities. Like the wire services that mobsters had once touted to bookies, Spread Network's offer was something high-frequency traders couldn't refuse—unless they just didn't have the money to pay for it.

"You had to have it to do arbitrage," says Bob Meade, who until 2010 ran a high-frequency trading group at Ronin Capital, a Chicago-based proprietary trading firm. Meade's group couldn't afford Spread Network's charges, however. "A good part of my business was completely undermined by this new technology," he says. But this unwelcome development got Meade—who had earlier earned a Ph.D. in physics from Harvard—thinking. In January of 2011, he teamed up with Stéphane Tyc, a buddy from his Harvard days who had also become a financial "quant," and they applied some obvious physics to the problem at hand.

Meade and Tyc knew that electromagnetic radiation travels only about two-thirds as fast in glass fiber as it does in air, and they wanted to make use of that fact to create *Continued on page 75*



The Long Life and Imminent Death of the Mag-Stripe Card

This love child of the airline and banking industries has survived for half a century. But the end is finally near

BY JEROME SVIGALS

IN 1967, THE AIRLINES WERE FLYING BOEING 727s and Douglas DC-8s. Air travel was still special, and the airlines were raking in cash. But a problem loomed, and it was potentially calamitous. The airlines had placed their orders for the first wide-body aircraft—the 747 and the DC-10—and these giant planes would dramatically boost the number of people arriving simultaneously at customer service counters. So to prevent chaos at those counters, the airlines had to find a way to speed up ticket sales and passenger processing.

Banks, too, were facing difficulties. Bank-backed credit cards were surging in popularity, and merchants were swamped with paperwork: Every time a customer charged an item, the merchant had to write out a charge slip and make a phone call to get the charge authorized. And all-night convenience stores and even the growing popularity of late-night television meant that people were no longer satisfied with banker's hours and expected banks to make services available on evenings and weekends.

The only way to solve these problems without hiring hordes of staff, for both the airlines and the banks, was to let customers serve themselves, with the help

PHOTO: LEVI BROWN; PROP STYLIST: ARIANA SALVATO

of a computer. For banks, that meant the ATM. For airlines, a similar kiosk could track reservations and dispense boarding passes. It would be easy enough to design a machine to spit out money or documents. But to get customers to trust these machines, engineers would first have to come up with a way to let users identify themselves that was fast, easy, and secure.

The answer turned out to be the magnetic-stripe card. Developed by IBM, it rolled out in the '70s, caught on globally in the '80s, and was essentially ubiquitous by the '90s. And in North America especially, it has withstood many challenges over the years to become one of the most successful technologies of the past half century. Consider the numbers: In 2011 alone, 6 billion bank cards around the world, along with transit tickets and other magnetic-strip media, went through card readers some 50 billion times.

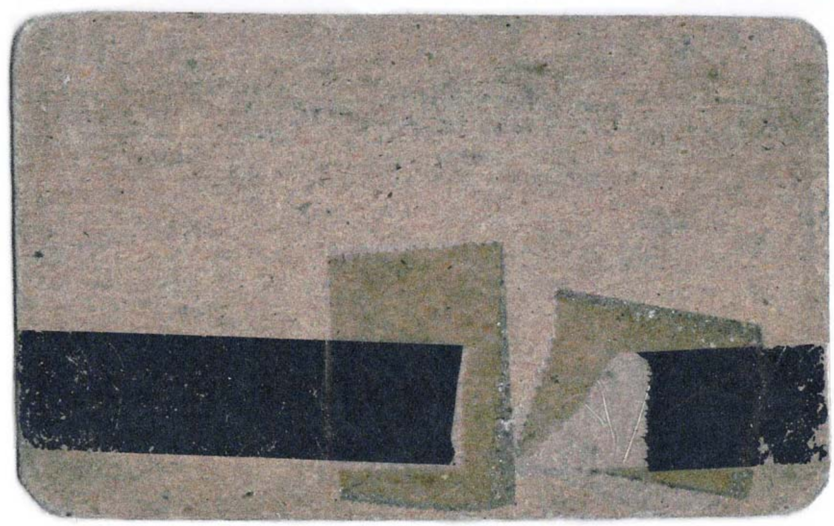
The biggest challenge came in the mid-1980s, when smart-card technology emerged. Smart cards look much like mag-stripe cards—indeed, most still contain a mag stripe for use where smart-card readers aren't available—but embedded within the plastic of the card is a microprocessor. That chip tracks the card's activity, which means that some 85 percent of transactions can be authorized just from the information stored on the chip, without going online—a boon where network access is spotty. They can also have hidden personal identification numbers—that is, the card can check a PIN entered by a user without revealing it to the equipment reading the card, which is a big improvement in security. In Europe and some other regions outside of North America, the mag-stripe card has been fully eclipsed by the chip-based smart card. The former has continued to thrive, however, in the United States and Canada.

But the end is finally in sight for the mag-stripe card. Even in North America, emerging smartphone-based pay schemes making use of Near Field Communication are now starting to catch on and will likely eventually replace the venerable charge plate. So as we head into a new era of tech-enabled transactions, it's a good time to sing the praises of the unsung engineering behind a technology that has been so stunningly successful.

CHECKING OUT: Magnetic-stripe readers moved into stores in the early '70s; this shoe store customer uses a mag-stripe card for payment in 1971. *PHOTO: IBM CORP.*

SO BACK WE GO TO 1967 AND THE struggles of the airline and banking industries to serve their customers without drastically increasing their customer service staffs.

Along came Big Blue to the rescue. At IBM's Advanced Systems Division, several hundred developers based in Los Gatos, Calif., and Armonk, N.Y., were charged with creating new computer applications to drive the sale of computers. The researchers came up with a card that was about the same size as existing raised-letter charge plates—and was readable by a machine. They



MAG STRIPE 1.0: Cellophane tape, a piece of magnetic tape, and cardboard created the first mag-stripe card. Author Jerome Svigals carries the prototype in his wallet to this day. *PHOTO: JEROME SVIGALS*

decided that a single machine-reading scheme should be used for both the airlines and the banks, saving the consumer from carrying multiple cards and IBM from having to manufacture different kinds of card-printing equipment.

IBM did the work for free and didn't even patent the machine-readable card it came up with. Rather, it offered its solution gratis to all comers, assuming that the more transactions conducted using machine-readable media, the more computers would be sold to process them. The strategy worked beyond anyone's dreams: By 1990, every dollar IBM had spent developing the stripe technology had returned US $1500 in computer sales.

IBM's engineers knew they wouldn't have a lot of room on the card for machine-readable data; charge plates measured 5.4 by 8.6 centimeters. The front of the card contained the bank's logo—that wouldn't change. The machine-readable section would share the back of the card with information about the bank and card issuer and a signature panel. The engineers concluded that they could count on having a strip across the card that was about a centimeter wide. So the size was easy to settle—1 by 8.6 cm. But how to encode the data on that strip?

IBM considered and rejected bar codes as well as perforated paper tape (an idea that Citibank would adapt for its short-lived "magic middle" cards). IBM eventually zeroed in on magnetics, used since World War II as an audio recording medium and more recently by the computer industry for disk storage. Only a magnetic technology could give the engineers enough data density to let them fit all the information they needed onto the strip. That data included both the alphabetic information, such as name and address—required by the airline industry to identify customers in its databases—as well as the numeric information that banks needed, including the account number and bank routing number.

IBM proved the concept with the world's first magnetic credit card: a piece of cardboard with the magnetic strip literally Scotch-taped to it [see photo, "Mag Stripe 1.0"]. And then came the real challenge: figuring out how to create a durable card that could be manufactured quickly and cheaply and would stand up to everyday abuse.

To get the magnetic material—iron oxide—to stick to the back of the card, the developers needed a binder that when heated would melt and attach the iron oxide to the plastic card. Happily enough, the same binder they were using to attach the signature panel worked fine with the iron oxide. Nevertheless, it took more than two years to develop a machine that could lay down the magnetic strips reliably at high speeds, and the per-card costs—at $2 each, or about $11 in today's dollars—were far too high. It took a decade—until 1980—for the cost of the cards to drop to an affordable 5 cents. Today, each card costs 2 or 3 cents.

MAGNETIC MEDIA has another problem. Counterfeiters can use a card skimmer to make a magnetic copy of a card swiped through it and then transfer that information to a blank card on the next swipe. The developers had to find a way to make the cards secure in spite of this weakness.

Some researchers deemed the problem intractable, arguing that the whole idea of magnetic cards should be abandoned. But others contended that large databases, just then coming into wide use, were powerful enough to track and analyze transactions and could compensate for the weakness of the cards themselves. The fact that IBM saw selling database systems as a prime business opportunity didn't hurt.

Here's how it works. When you or a checkout clerk swipes your credit card, the card reader captures the information encoded on the mag stripe that identifies you. That terminal—using either dedicated connections or, in the case of some smaller merchants, a dial-up line—forwards the information about you and the amount of your desired purchase to the bank that collects your card payments, which then passes it on to the card issuer via a card network like Visa. If the issuer determines you have enough credit, it sends an approval message to

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THE FUTURE OF MONEY

What's on Your Card?

Each magnetic stripe card contains three recording tracks, each 0.28 centimeter wide, with a small intertrack recording separator.

1 TRACK ONE: AIRLINES
- 79 alphanumeric characters
- 7 bits per character
- 210 bits per inch density

2 TRACK TWO: BANKING
- 40 numeric characters
- 5 bits per digit
- 75 bits per inch density

3 TRACK THREE: READ/WRITE TRACK
- Used for other purposes, including driver's licenses and savings and loan industry
- 107 numeric characters
- 5 bits per digit
- 210 bits per inch density

MARCUS LINDSTRÖM/ISTOCKPHOTO

the bank, which forwards it on to the store. This normally takes just seconds. But the credit card issuer isn't quite done with your transaction. Even after the sale is authorized and you walk away with your purchase, fraud-checking software at the card issuer examines the transaction to see if it fits in with your usual purchase patterns or flags it if it doesn't.

After settling on the mag-stripe technology, the developers had to figure out how to place the data on each card. They initially thought to include all the information—the numeric codes for the ATMs and the alphanumeric codes for the airlines—in a single set of data and let the machine readers sort it out. Then they hit on a simpler solution—multitrack recording, a relatively new technology that would allow them to encode two separate sets of data on a single magnetic strip. This scheme allowed IBM to get out of the way—each industry could then go off and create standards for its own track. There was even enough room for a third track, one that allowed the savings and loan industry to record transaction information on the card itself.

Each of the three tracks is 0.28 cm wide, with a small intertrack recording separator. Track One, allocated to the airline industry, includes, among other data, the account number (19 digits), name (26 alphanumeric characters), and miscellaneous data (up to 12 digits). Track Two, allocated to banks, contains the primary account number (up to 19 digits) and miscellaneous data (up to 12 digits). That very same format is still in use today.

IN JANUARY 1970, American Express issued 250 000 mag-stripe cards to its Chicago-area customers and installed self-service ticketing kiosks at the American Airlines counter at Chicago O'Hare International Airport. Cardholders could opt to get their tickets and boarding passes from the kiosk or from a human agent. They flocked to the kiosks. In fact, United Airlines customers walked to American Airlines—at the other end of the terminal a quarter mile away—to use the kiosks.

The mag-stripe technology quickly became the ubiquitous mechanism for transactions. Its persistence in North America has been a result of happenstance as well as good design. When smart-card technology became available in the mid-1980s, the major credit card issuers had just spent tens of millions upgrading their North American networks. Going to a smart-card technology would have made much of that investment superfluous.

With that outlay largely amortized by now and security problems growing, the industry isn't so wedded to the mag-stripe card, and smart cards are finally trickling into North American wallets. But smart cards will have a short reign in North America because mobile phone–based transactions will quickly supplant them.

Today, every new point-of-sale device designed to process transactions can also communicate with smartphones using a set of wireless standards called Near Field Communication. North Americans and Asians aren't using this capability that often yet, but it is increasingly available [see "Phone-y Money," in this issue]. Meanwhile, some airlines have already installed readers that eliminate the need to use a self-service kiosk—passengers simply present an electronic boarding pass displayed on their smartphones.

Ironically, one of the most recent technical developments, Square—a tiny plastic attachment that turns smartphones into card readers and allows anyone to accept credit card payments—may actually slow down the rate at which mag-stripe cards give way to smartphone-transaction technology. Square makes it simpler for people to continue to use mag-stripe cards rather than migrate to new systems.

Over the next few years the mag-stripe card will fade away. But its legacy will live on. The original information standards—the way the data is physically laid out on the mag stripe—has survived every migration of transaction media, from mag-stripe cards to smart cards, from smart cards to smartphones. And just as many of us have forgotten the origins of the QWERTY layout of the keyboards we tap on for so many hours each day, we'll soon forget—as we snap photos of checks to deposit them, wave our phones across scanners to pay for our lattes, and glide through turnstiles in mass transit without even removing our phones from our pockets as our accounts are automatically debited—that it all started with a magnetic stripe. ❑

Write to us at http://spectrum.ieee.org/magstripe0612

THE MICROSECOND MARKET

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an especially fast communication link between New York and Chicago. They considered using short-wave radio signals, which follow Earth's curved surface and can thus travel long distances. But they found that the only frequencies available for that were in the amateur bands, where business communication is forbidden. They also thought about relaying radio signals with high-altitude balloons, but they decided that was too crazy, even for them.

Eventually Meade and Tyc settled on a more straightforward solution: a chain of fixed microwave towers. They calculated that a properly engineered microwave connection could handily beat Spread Network's fiber-optic offering. Then they formed a company, McKay Brothers, named after the Gordon McKay Laboratory for Applied Sciences at Harvard, to build it. "We thought we were the only geniuses in the world to think of this," says Meade. But as soon as they examined the Federal Communication Commission's database, they discovered otherwise. Meade says that there are now about a dozen companies working on microwave links that will compete with the one they expect to complete within a few months. (Meade declined to give a total cost for the project, but he did say that he and Tyc were funding the project themselves, without outside investors.)

Meade believes that his and Tyc's backgrounds in both physics and finance give them an edge here. Others, he says, are designing their microwave systems very conservatively, as electrical engineers are apt to do: They site their towers within 50 kilometers or so of one another and shun over-water stretches, which sometimes prove a challenge for these radios. The McKay Brothers route goes over both Lake Michigan and Lake Erie and includes hops between towers that are often twice the normal distance limit. It also follows the shortest path possible over Earth's surface (a great circle) or very nearly so. "It's a 740-mile [1191-km] route, and we're 4 miles from perfect," says Meade. "We considered latency at every decision point."

Won't those latency optimizations compromise reliability? Perhaps. But Meade argues that high-frequency traders would much rather have access to a communications channel that's faster than every one else's, even if it gets flaky every now and then. A link that's second or third fastest isn't of much use to them, even if it's always available. That's a very different calculus than the one most engineers use—but it's clearly the one you want to follow if you're trying to get ahead of the pack.

What next? A fast link for transatlantic high-frequency trading. Hibernia Atlantic of Summit, N.J., is now working on a project to connect high-frequency traders in New York and London with an especially direct undersea cable, something it calls Project Express. Mike Saunders, vice president of business development at Hibernia, says that the route is being surveyed now and that the new fiber-optic cable will be laid next year, as soon as winter storms on the North Atlantic abate, with the link becoming operational soon after.

This $300 million project will reduce the travel time for signals between New York and London to something less than 30 ms, which is a couple of milliseconds faster than any fiber-optic connec-

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tion now in place. Saunders says that Hibernia has customers already signed up for the new link—all high-frequency traders. "There's nobody else who will pay the same price," he says.

THE RISE OF HIGH-frequency trading over the last few years certainly raises the technological bar for anyone attempting to make money off fleeting inefficiencies in financial markets—say, from short delays in how fast prices are calculated or from slight lags in the flow of information from place to place. You now need state-of-the-art servers located at the exchanges' data centers, low-latency networking hardware, and the fastest possible long-distance data connections. Things have come a long way from a few telegraph wires linking racetracks with seedy back rooms.

Many people don't see much point to the technological arms race that now lets only the best-equipped companies profit from high-frequency trading. Michael Wellman, a professor of computer science and engineering at the University of Michigan who studies electronic commerce and automated trading, has suggested that a better solution might be to move away from today's continuous electronic trading toward a discrete-time market mechanism. This would be what those in finance refer to as a call market, but on a very short timescale.

> **Wall Street might seem the epicenter of U.S. stock trading. In fact, the real action takes place about 50 kilometers away, in a huge, windowless building in suburban Mahwah, N.J.**

According to Wellman's concept, anyone could submit electronic orders to trade anytime, but no one would have access to information about those orders until they cleared at the end of some discrete interval, say one second. That would remove the advantage high-frequency traders gain from their microsecond-level optimizations, but it wouldn't otherwise interfere with the trading of ordinary investors or other businesses. "You could run a call market fast enough that nobody would complain that they had to wait too long," says Wellman.

To IIT's Van Vliet, such proposals are unappealing, even anachronistic. "You can't stop progress," he says. But he also recognizes that there are dangers lurking in today's highly automated trading infrastructure. If your firm's trading system goes haywire, "not only would you lose a lot a money, you'd also destabilize the market," he says.

To avoid such disruptions, Van Vliet argues, the financial industry needs to develop technical standards for its equipment and software—just as, say, the airline industry has done—so that it doesn't put the public at risk. But it'll surely take a while yet before protecting the public becomes a high priority on Wall Street or at the world's other financial centers. "Trading has gone from a gambling problem to an engineering problem," says Van Vliet. "But the culture of financial markets is still a gambling culture." ❏

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the data

The High Cost of Money

Whether you pay for a bag of groceries by cash, check, credit card, or debit card may seem to be just a matter of convenience. But the cost to you is nothing like the cost to the seller, says Allan Shampine, senior vice president of the Chicago financial consulting firm Compass Lexecon. "If it's a mom-and-pop store and you get out your credit card, the merchant is probably groaning inside: 'He comes here all the time. I really wish he'd pay with cash!' "

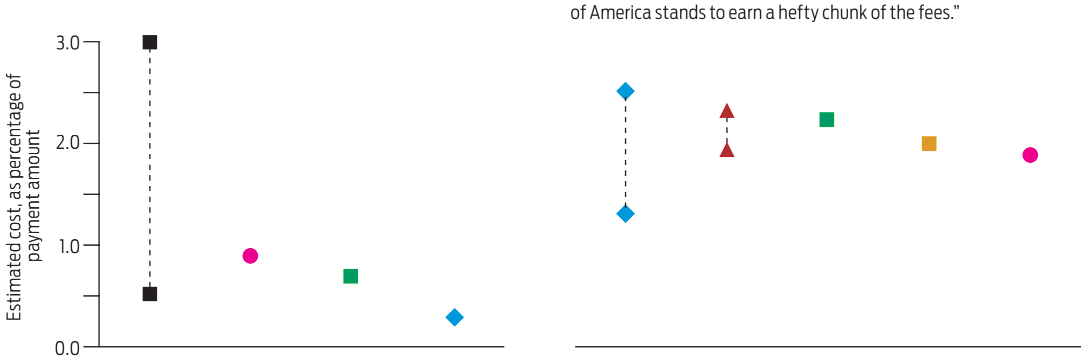
In January, Shampine published a survey of 11 studies from the past 21 years of the actual costs of various payment methods. Shampine was surprised to discover that estimated costs of cash versus credit cards versus debit cards or checks vary so widely that only a fuzzy picture emerges.

Below are some sample findings—along with Shampine's commentary on parts of the story that the data might not be telling. —*Mark Anderson*

CASH A comprehensive study by the armored car service Brinks found that keeping cash was cheaper for some businesses than it was for others. Shampine explains that accepting cash incurs fixed costs—cash registers, vaults, cash counters, and armed guards, to name a few—that larger enterprises can amortize better than smaller ones can. "When you see someone who has a cost of 3 percent or more, that's someone who's not dealing with a lot of cash," he says.

CREDIT CARDS If a single, uncontested fact emerged from Shampine's study, it's that credit card transactions are expensive—though, unlike those carried out with cash, they consist almost entirely of bank fees. "If you pull out your Bank of America Visa card, the merchant calls up its bank—say that's Chase," says Shampine. "Chase will then connect through the Visa network to Bank of America and ask for the transaction to be approved. Bank of America stands to earn a hefty chunk of the fees."

■ Brinks "State of Cash," 2008
● Food Marketing Institute, 2000
▲ Food Marketing Institute, 2010
■ Bank of Canada, 2008
◆ Coopers & Lybrand, 1995
■ Nilson Report/*Lydian Payments Journal*, 2010



SIGNATURE DEBIT In the United States, a debit card can either be one of the cheapest or most costly forms of payment. If the merchant uses the debit card as an ersatz credit card, thus requiring a signature, the transaction follows the comparatively expensive networks set up for processing credit cards. By contrast, says Shampine, in Canada just a PIN is needed, for a flat fee of 12 cents per transaction.

PIN DEBIT Within these numbers is a hurricane. In October 2011, a key amendment to the Dodd-Frank Wall Street Reform and Consumer Protection Act came into force. It empowered the U.S. Federal Reserve Bank to determine a maximum amount banks could charge merchants for a PIN debit card transaction. The Fed came up with 21 cents—drastically up from an initial 2010 estimate of 12 cents. Naturally, merchants didn't like the higher rate. Some are suing the Fed. One is the Food Marketing Institute, whose studies of transaction costs are cited here.

CHECKS Sources for the checks studies are aging—for good reason. Check usage is on the decline [see the related story online]. If anything, Shampine says, transaction costs for checks have probably declined a little. "The processing has gotten more efficient," he says. "Nobody ships paper checks anymore." Instead, payment data is just a scan of the paper check—transmitted electronically from bank to bank.

SOURCES: Bank of Canada; Brinks; Coopers & Lybrand; Food Marketing Institute; *Lydian Payments Journal* (using Nilson Report data), January 2010; "An Evaluation of the Social Costs of Payment Methods Literature," Allan Shampine, 12 January 2012, posted on the Social Science Research Network on 14 January 2012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