

## TOP 11 TECHNOLOGIES OF THE DECADE

The most powerful technologies take a while to mature. But when they do, they can rapidly retire mainstays that are decades old

**LIFE WAS DIFFERENT A DECADE AGO.** Your phone couldn't contain your entire music collection, for example, or guide you to a restaurant in a foreign city. Bomber-reconnaissance planes invariably had pilots on board. And how's this for quaint: Your corner drugstore still stocked photographic film! The technology waves that washed away those realities spread from tremors that occurred years before: The first smartphone was unveiled by IBM in 1993, the first digital photo was taken in 1975, and the first drone aircraft flew during World War II. Clearly, the seeds of the next crop of technology staples have already been planted. Perhaps the first tender shoots can already be discerned among the pages of this issue. —*Philip E. Ross*

# NO. 1 Smartphones

## IS YOUR PHONE SMARTER THAN A FIFTH GRADER?

**Yes**

DOUGLAS ADAMS's *Hitchhiker's Guide to the Galaxy* series is named after a pocketable device that contains everything worth knowing. But that seems almost quaint today, when you can carry the full contents of the Web in your pocket, as well as a telephone, a camera, a radio, a television, and a navigation system. Today's smartphones are marvels of engineering, crammed with more features than the average PC. They've become the prime driver of innovation for both software and hardware.

It took half a century to shrink the mainframe from the size of a living room to that of a suitcase. It took another decade to make it smaller than a wallet. The smartphone has swallowed and assimilated functionality from music players, remote controls, gaming consoles, even printed maps and news publications. And now that smartphones are serving as Wi-Fi hot spots, they can replace wireless routers and modems, too. Smartphones are becoming as essential as keys or a wallet, and they'll soon

replace those as well [see "Company to Watch"].

This has some real consequences. Unlike its predecessors, the smartphone is an inherently personal device: Not only is it always on, it's always somewhere on us. Without realizing it, we've let smartphones usher us into an age of ubiquitous, pervasive computing that technologists, as well as science-fiction authors, have been dreaming about for years.

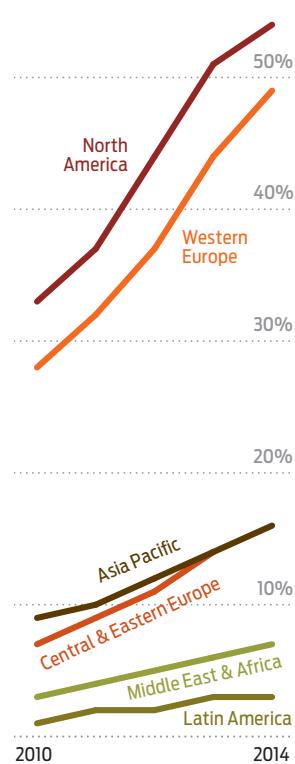
"Smartphones help users stay connected to information at any given time, any given location," says Dilip Krishnaswamy, a Qualcomm engineer and associate editor in chief of *IEEE Wireless Communications*. "The information is just there when you need it."

We've come to rely on such connectivity. There's no need to pack a map or directions when an app can guide you in real time, nor to consult a restaurant guide before leaving the house. In these and a thousand other ways, the smartphone, more than any other technology to have emerged in the past decade, is the one that has most changed our lives.

To be sure, back in 1973, Motorola's Martin Cooper didn't set out to build an always-connected, portable computing device. He was simply trying to shrink

### NOT ALL SMART YET: Projected smartphone penetration

PERCENTAGE OF ALL MOBILE PHONES



Smartphones are proliferating rapidly, but they still make up a minority of all mobile phones. Customers in North America have been especially quick to embrace them, but Italy still has the highest concentration in the world. The low percentage in Asia is due partially to the popularity of advanced feature phones (which have many capabilities but lack a true general-purpose operating system) in Japan and South Korea.

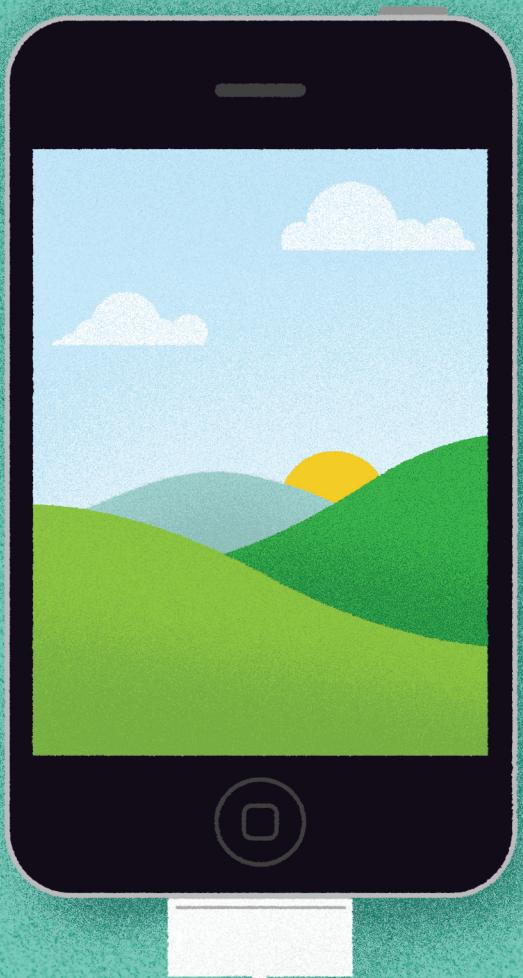
*Source: Cisco Visual Networking Index, February 2010*

the car phone down to the size and weight of a luggable brick. But once the cellphone had earned a permanent place in our pockets, it became an unavoidable platform for innovation, upstaging the PC. If Starbucks wants to make it quicker and easier to pay for a cup of coffee, why not do it through the phone? If *The New York Times* wants to get away from paper, well, everyone's already carrying around a perfectly readable screen.

Smartphones are more than just bells and whistles—they actually change behavior. With a traditional mobile phone, users spend most of their time making calls and sending text messages. On a smartphone, basic communication takes a back seat to Internet browsing, e-mail, entertainment, and games. This difference is due to three key ingredients, each of which has seen tremendous advances in the last decade: hardware, software, and network infrastructure.

The hardware is the most obvious. Thanks to high-resolution displays with touch screens or QWERTY keyboards and tiny camera lenses on the outside and gigahertz processors, radio antennas, and image sensors on the inside, the phones hardly resemble their modest predecessors.

But at least as important is the software. "The operat-



**COMPANY TO WATCH:** BROADCOM CORP., IRVINE, CALIF.

If you want your phone to replace your wallet and keys, it will need a near-field communications (NFC) chip. Broadcom already supplies companies like Apple with integrated Wi-Fi and Bluetooth chips, and thanks to its August 2010 purchase of UK-based Innovision, the company should soon be able to add NFC for less than US \$1 per unit.

ing system is the foundation for everything else in a smartphone," says Donna Dubinsky, a cofounder of Palm, the company that first succeeded in cramming computer functionality into a pocketable device. Every major smartphone operating system now supports third-party applications that extend the phone's capabilities far beyond what any one manufacturer can do.

And in addition to using the resources of the phone itself, these apps can off-load data storage and processing to the cloud [see "It's Always Sunny in the Cloud," in this issue], in the form of server farms around the world, thanks to ever increasing wireless bandwidth—the third key development behind the smartphone. "People naturally want to focus on the device itself," says Dubinsky, "but what's important is the complete system, including hardware, software, and application development environment."

Current smartphones quietly shift between Wi-Fi

**BET YOU DIDN'T KNOW**

South Korea, which has long boasted the world's fastest data connections, saw average Internet connection speeds slow by 24 percent in 2009. Blame the iPhone: It made its debut on the country's slow wireless networks and was then widely adopted.

and 3G so that users are always connected to the best available network. Remember that the iPhone, still less than four years old, didn't even access 3G networks when it launched. By October of last year, you could get a 3G signal at the top of Mount Everest, and now the first 4G networks are emerging.

Today we're seeing only hints of how a smartphone world will be different. With their numerous sensors, they will form nodes in a vast and unprecedented data collection network. Researchers have already used phones' accelerometers to follow basic health indicators (such as a patient's gait), their GPS to monitor crowd and pedestrian traffic patterns, and their microphones to track bird migrations. Several app developers have created the first useful examples of augmented reality—letting you point your phone at a restaurant and see a bunch of customer reviews, for example.

These capabilities come with strings attached, notably the addictive effects of always-on connectivity. BlackBerrys are rightly nicknamed "CrackBerries" for the way they feed a workaholic's addiction. Krishnaswamy notes that we're training ourselves to always be ready for the next e-mail or status update, and we're disappointed when one doesn't arrive. And not everyone likes it when people interrupt dinner to surf the Web to fact-check the conversation.

Some experts even worry about a new digital

**HOW PHONES GOT SMART: EIGHT MILESTONES****IBM SIMON PERSONAL COMMUNICATOR [1993]**

IBM was ahead of the curve back in 1993. The Simon was a touch-screen phone with a calendar, address book, calculator, and even the capability to send and receive e-mails and faxes. It was impressive, but also bulky, and came with a hefty price tag: US \$899.

**NOKIA 9000 COMMUNICATOR [1996]**

If you wanted a smartphone in the late 1990s, your choice was pretty much limited to the pricey Communicator. The device was like a personal digital assistant and a mobile phone sandwiched together. (It's rumored that an early prototype was actually a Hewlett-Packard PDA connected to a Nokia phone by a hinge.)

**ERICSSON R380 [2000]**

The R380 was one of the first phones actually marketed as a "smartphone." It was the first commercial phone to run the Symbian OS. Symbian has long been the most common smartphone operating system, but its market share has rapidly declined since it began facing competition from Apple's iOS and Google's Android.

**SONY ERICSSON P800 [2002]**

The P800 came with several new features that we consider standard for smartphones today: It could play MP3s, came with a camera, and featured a color touch screen (although it supported only 4 096 colors).

**RIM BLACKBERRY 6210 [2003]**

Research in Motion's early communicators offered two-way text paging, but the company soon realized that push e-mail service was its killer app. RIM developed a QWERTY keyboard for quick thumb typing and BlackBerry Enterprise Servers to tap into existing e-mail infrastructure. In addition to e-mail and basic Web browsing, the 6200 series were the first BlackBerrys that were also fully integrated phones (earlier models required a headset).

**PALM TREO 600 [2003]**

The Treo combined some of the best features of the Palm Pilot PDAs with a mobile phone shape, creating a smartphone that had appeal beyond business users. With its Palm OS, the Treo supported lots of third-party apps. Palm OS also gave the Treo integrated functions, like the ability to dial directly from the contact list and check the calendar while on the phone.

**APPLE iPhone [2007]**

Apple's much anticipated iPhone immediately obliterated the competition. Its multitouch, capacitive touch screen encouraged users to interact using their fingertips, and the mobile Safari browser made mobile Web browsing fun, not just possible. Apple also used its clout to upend the mobile ecosystem, wresting unprecedented control from carriers. The iPhone 3G upgraded the data connection and launched the wildly successful app store.

**HTC EVO 4G [2011]**

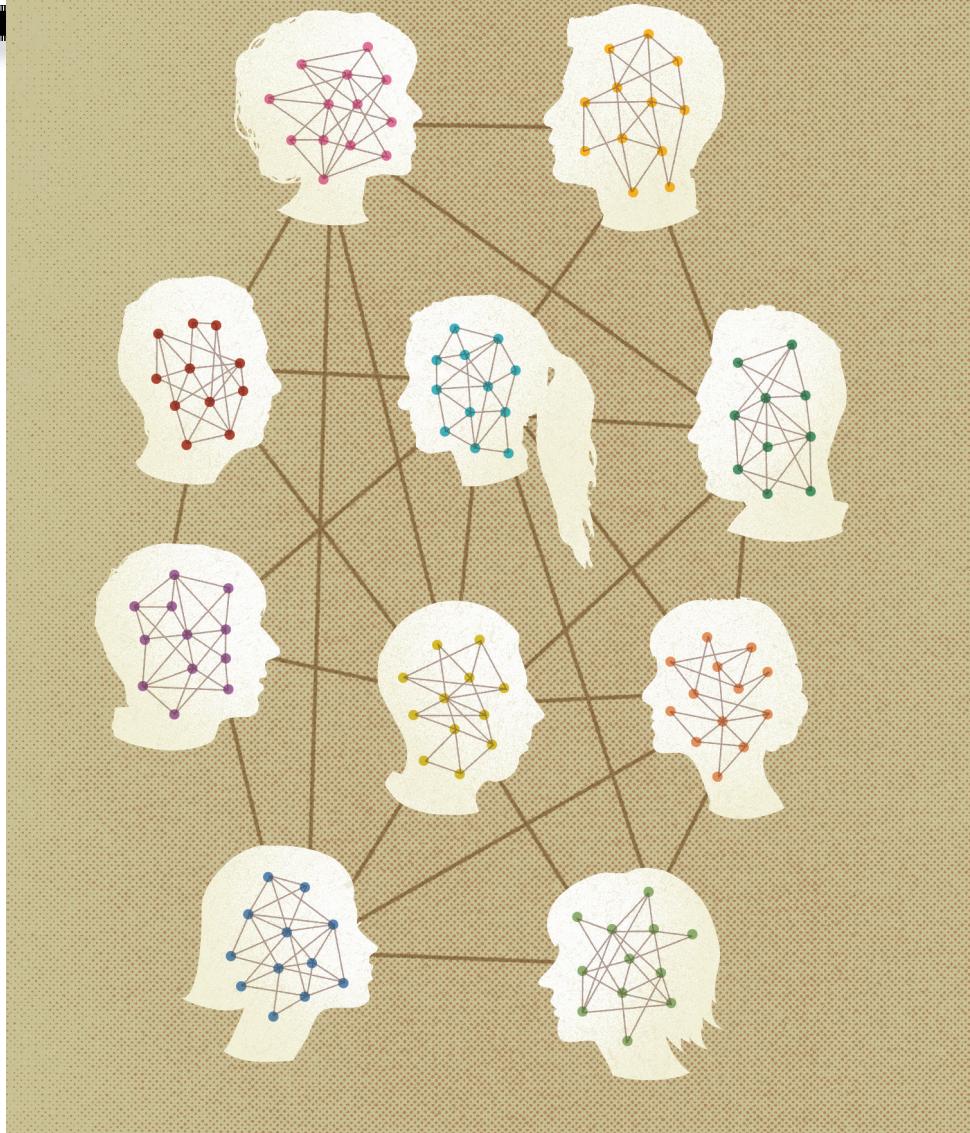
At launch, the EVO 4G was arguably the best Android smartphone around: It had an 8-megapixel camera that could shoot HD video, HDMI output, and a 4.3-inch touch screen. But its best trick was the ability to act as a mobile hot spot connected to Sprint's WiMax network, the fastest data network in the United States at the time.

divide between those who can afford smartphones and data plans and those who can afford only basic mobile phones. In fact, many smartphones cost more than low-end computers, once you take away the subsidized prices that wireless carriers offer for them. Yet in rural and impoverished areas, they represent a much better investment because they're self-contained, needing neither additional network infrastructure nor even reliable power.

In any case, many high-end features will inexorably filter down to low-end phones, as they have in the camera market, and what begins as a luxury will quickly become a necessity. In 2007, sales of smartphones surpassed sales of laptops, and some predict that by 2014 more people will browse the Internet by phone than from traditional computers.

The drive to communicate on ever-wider scales has shaped many of our technological advances, and these in turn have shaped how we communicate. Moving from text messages to Twitter updates, from voice to video chat seems to be part of our evolution. "The interesting thing is how it's changing human behavior itself," says Krishnaswamy. "Smartphones will become a sixth sense for the user, gathering information from wireless sensors in the user's environment and from the network, interpreting the information, and providing valuable feedback to the user."

—JOSHUA J. ROMERO



# No. 2 Social Networking

## FRIENDED

**Bandwidth, digital cameras, and a hunger for connectedness have created a virtual dinner party**

A DECADE AGO, it might have taken a new person in town months to make

contacts, find places to hang out, and meet like-minded people. Now, with a few clicks of the mouse, you can get the job done through social networking—a communications revolution that began in fits and starts in the late 1990s and reached recognizable form

in March of 2003, with the public launch of Friendster.

"The idea was to have the Internet do the work of a dinner party," says Kent Lindstrom, a former Friendster CEO. A user could set up a profile, with personal facts and a picture, and invite friends to join. Friendster's servers

## COMPANY TO WATCH: NING, PALO ALTO, CALIF.

Launched in 2005 by Gina Bianchini and Netscape cofounder Marc Andreessen, Ning is betting on small, exclusive networks. Already the company hosts 2 million customized social networks, including Shred or Die, for extreme skateboarders, and GovLoop, for anyone working in government.

would then generate a continually updated list of her friends as well as her friends' friends, mapping relationships out to four degrees of separation. Within nine months, Friendster had a million members.

Around that time, *Fortune* magazine prophesied, "There may be a new kind of Internet emerging—one more about connecting people to people than people to websites." Indeed, such an Internet has emerged, though, as so often is the case, the first movers have been left behind. The big winner has been Facebook, founded less than a year after Friendster went public. Facebook has 540 million users who spend about 700 billion minutes on the site every

month; if it were a country, it'd be the third most populous in the world.

**YOU CAN LIVE** much of your life in that strange, virtual country. Matthias Galica, 26, founded ShareSquare in May 2010 to enable users to print bar codes to "geotag" objects in the real world so they could be followed in the virtual one. The day he moved the business into a loft in downtown Los Angeles, he got an e-mail message through his Facebook account from one of his more than 1400 "Facebook friends" inviting him to join the Facebook group DTLA.

He clicked the "Accept Invitation" icon, which connected him instantly to hundreds of like-minded Los Angelenos. Later that

night, at a concert, he used his iPhone to log into Foursquare, a friend-locator service, which automatically posted the message "Matthias just checked-in @Shrine Auditorium" to his Facebook page, prompting an impromptu get-together with another member of DTLA.

"Connections that would've taken months now happen in a space of hours," Galica remarks.

This is exactly the kind of life promoted by Friendster, which was left in the dust by MySpace, which was lapped by Facebook. Yet even Friendster climbed up on the shoulders of still-earlier pioneers. The most notable was Sixdegrees, arguably the first true social network. Twenty-eight-year-old New York businessman Andrew

Weinreich launched Sixdegrees at a party in 1997, announcing that "with the click of a button," the site would revolutionize human networking. Like Friendster, Sixdegrees let users identify their friends, their friends' friends, and so forth. At its peak in 1999, it had attracted 3.5 million members.

But each of these early actors came too early or learned a critical lesson too late to dominate. For Sixdegrees, the major flaw was the absence of photographs. "We had letters coming in all the time asking, 'If I mail in a picture, can you scan it for me and put my picture on your site?'" Weinreich recalls.

**FRIENDSTER AND ITS** rivals came around at just the right time. Point-and-shoot cameras were ubiquitous. Broadband was cheap and available. Users could be sure that the friends they invited to see their profiles and chat online had high-speed Internet connections and plenty of photos to share.

But Friendster made a single, master mistake: It took on customers faster than it could manage them. By the end of 2003, Friendster was acquiring some 9500 users a day, and the company was struggling to buy enough servers to keep up with the growth. Users complained that their home pages regularly took more than a minute to load.

Their frustration paved the way for MySpace, a Los Angeles start-up founded by hackers Chris DeWolfe and Tom Anderson. They did away with pesky friend

## HONORABLE MENTION

**E-paper****Paper or Plastic?**

In 2020, newspapers will still be with us, but they won't be paper

Despite the increasing sophistication of electronic displays, with their staggering color palettes and expanding contrast levels, Gutenberg's 15th-century technology didn't begin to give way until the 2000s. That was when electronic paper made its debut in digital book readers like Amazon's Kindle and Barnes & Noble's Nook.

E-paper exploits a phenomenon called electrophoresis, discovered in 1807 and revived at Xerox PARC in the 1970s but put to practical use at MIT's Media Lab only in 1997. It uses a jolt of current to make the

black dye inside thousands of microcapsules sandwiched between flexible polymer sheets rise to the top of the capsules so that the "ink" becomes visible through one of the sheets. A great advantage of this method is that it draws power only when updating the image on the screen. Recent models offer a contrast ratio similar to that of a newspaper.

Speaking of the dailies, they just may supplant books as the killer app for e-readers. Uploading a digital version of your hometown broadsheet on a plastic sheet that you can roll up and tuck in your bag would eliminate the cost of printing and distribution, and it'd also save a lot of trees.

—Willie D. Jones



## BET YOU DIDN'T KNOW

Social networks are proving to be gold mines for predicting human behavior. In a proof-of-concept study, scientists at HP Labs used movie chitchat on Twitter to accurately predict box office hits. And the police department of Richmond, Va., is now using network-analysis software to monitor Facebook, MySpace, and Twitter for evidence of crime incubators, such as rowdy parties.

calculations and instead let users cruise the entire public site, eavesdrop on strangers, create bizarre “fakester” profiles—notably those of Jesus and of the Burger King—and make their own connections. MySpace’s meteoric success (72 million members in 70 countries by 2007) led to a boom of businesses that New York University social-software analyst Clay Shirky labeled “YASNS,” as in “Yet Another Social Networking Service.”

For instance, there’s the messaging service Tencent QQ, which is popular in China; Google’s Orkut, which is popular in Brazil; and Twitter, a blogging network that limits posts to 140 characters, which is popular just about everywhere. There’s Flickr for photo sharing and YouTube for video sharing. There’s LinkedIn for job networking and Classmates for finding long-lost school friends. And there’s a whole host of niche networks: Coastr for beer aficionados, Goodreads for bookworms, ResearchGATE for scientists, and Dogster for dog lovers.

The reign of MySpace, however, didn’t last long. By September 2009, the company could claim just 30 percent of the American social-networking market, down from 67 percent the year before, according to the research firm Hitwise. Its biggest mistake was losing control of the site’s usability. Rather than develop tools that would help users organize the vast amounts of shared information, MySpace dumped all its resources into new features

it thought would drive traffic: bulletin boards, job listings, horoscopes, even a YouTube-esque video-sharing service called MySpaceTV. The site got so cluttered that many users left to look for something simpler.

**FACEBOOK CONQUERED** in part because it took to heart the lessons of its predecessors’ mistakes. For instance, its founder, Mark Zuckerberg, expanded from the company’s base at Harvard by adding one university at a time, ensuring that no new customers would come online until the servers could handle the additional traffic.

Facebook also lured Internet users with its sleek, easy-to-use interface and engineering wizardry. One of its most innovative features was Multi-Feed, which searches your friends’ databases for new updates and streams them to your home page as a continuous news feed. Facebook now contends with some 30 billion shared updates a month—a monumental processing feat that requires tens of thousands of servers.

When the feed was introduced, some veteran users derided it as an intrusive assault on their privacy. But most of them stayed to gawk, and many new users poured in because of it. Each new attempt to expand Facebook’s reach has prompted renewed criticism that the company allows users too little control over their own data.

Rival sites have rushed

to fill the possible privacy gap. Diaspora, a New York University student-built network, lets users program their own servers rather than rely on a centralized system. Ning, based in Palo Alto, Calif., offers a do-it-yourself social-networking platform for tight-knit communities. Next up could be Google Me, the search giant’s most recent foray into the social-networking business. However, it seems that Facebook is here to stay.

“Their scale makes them formidable,” says Weinreich, who believes that Zuckerberg has successfully constructed the ultimate “social graph”—a term for the web of relationships the 26-year-old billionaire popularized in May 2007, when he announced to a warehouse full of programmers in San Francisco that he was opening up Facebook’s infrastructure to anyone wanting to run programs on it. Little more than three years later, Facebook’s social graph has become a powerful business platform. Independent software developers have coded a cumulative 550 000 applications for Facebook users. Some are absurd. SuperPoke, for example, lets users virtually “kiss” or “spank” their friends. Others, particularly multiplayer games, such as Zynga’s *Mafia Wars* and *FarmVille*, have cultivated multimillion-dollar businesses.

To spread Facebook’s influence even further, its engineers created

Facebook Connect, a software-to-software communication tool (an application programming interface, or API) that lets Facebook users log in to their iPhones or other Web sites—the news aggregator Digg, for example—with their Facebook identities.

Joe Stump, the chief technology officer of SimpleGeo, which helps location-based services collect and manage data connected to places, predicts that soon your Facebook identity will follow you wherever you go. You’ll use it to decide, based on friends’ recommendations, which book to buy or which doctor to see. It’s likely, then, that geo-networking apps such as Foursquare and its closest competitor, Gowalla, will be the next big thing online.

Again, it will be the mass adoption of new consumer technologies—this time, smartphones and cloud computing—that will allow people to collect and compute vast amounts of data about places and things. The trend has already begun. “We’re heading into a third phase of the Web,” Stump says.

The webs between humans and machines, and between humans and the people they trust, have already been spun. The Web of the future will instead connect our physical world with our virtual one, enabling our online social interactions to give us valuable insights into our off-line lives.

—ARIEL BLEICHER

# No. 3 Voice Over IP

## SETTING PHONE SERVICE FREE

### How Ma Bell's cash cow became a free software app

**FOR GENERATIONS** it was possible to grow up and grow old without outgrowing the telephone of your youth. Handsets stayed tethered to the wall, “long distance” remained a concept, costly service was a given. Then in the 1990s, when competition and cellphones began to free us from wires and monopolistic pricing, we marveled at what seemed a revolution. We were wrong: The real revolution began only in the 2000s, when it became clear that the Internet would be the telephone network of the world.

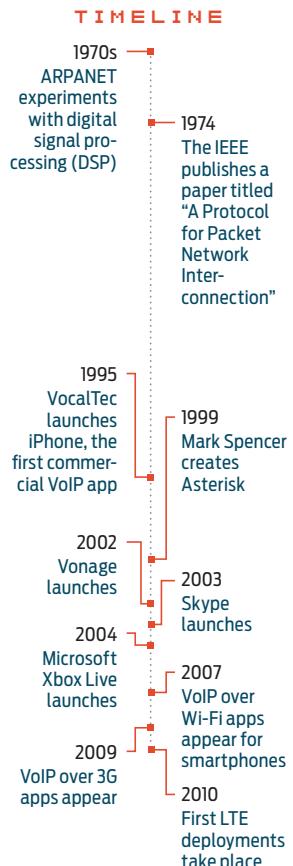
Look at this one fact: Skype, which launched only in 2003, now has more than half a billion registered users, making it the largest provider of telephony services in history. It’s good for Skype, but better still for its users, who when they talk Skype-to-Skype pay exactly nothing, no matter where they may be on the planet. The company charges only when you call a phone listed on a “real” telephone network.

It is at that junction, in the increasingly hazy no-man’s-land between the

telecom and Internet worlds, that the revolutionary insurrection is playing out.

**EXACTLY WHEN** Internet telephony began is unclear. By all accounts the guys behind ARPANET, the predecessor to the Internet, experimented with digital signal processing in the 1970s. But the main story begins, at the earliest, in 1989, when Alon Cohen and Lior Haramaty, two graduates from the Israeli Defense Forces telecommunications wing, founded VocalTec Communications, in Herzliya, Israel. Following on from what they’d seen in the military, where packetized voice was already being used to deliver sensitive orders and intelligence, the entrepreneurs experimented with commercial sound cards for desktop PCs. They became experts on digital sound at a time when most technologists were still squinting at green monochrome monitors; in fact, people used to ask Cohen and Haramaty why they weren’t trying to deliver color rather than sound to the PC terminals of the day.

Meanwhile, they faced down potential disaster when a better-funded competitor, Creative Technology, based in Singapore, arrived on the scene with the Sound Blaster, a sound



integrated telephony—you wouldn’t need to install new hardware.”

Cohen and Haramaty first aimed at the level of the local area network, which in those early days meant the in-house telephone systems of companies. They relied on the User Datagram Protocol (UDP), a quick but not particularly reliable way to break a voice signal into packets of data and reassemble them at the other end of the call. They anticipated that packets could get lost, might arrive late and out of sequence, or be corrupted by jitter—the loss of transmitted data between networked devices.

Therefore, the technologies to solve these problems were all in VocalTec’s products from day one, although it turned out they weren’t needed. “When we tried the service on the local area network, the network was so good that we didn’t need any of these mechanisms at all,” Cohen says. “So we started selling this product, and people started using it between their office networks in the UK and the U.S. to save money on long-distance telephone calls, because calls were very expensive back then. And that was the trigger for delivering this same service over the public Internet.”



## COMPANY TO WATCH: VIVOX, NATICK, MASS.

Founded in 2005, Vivox provides voice chat services for online games and virtual worlds. Supporting over 25 million users in more than 180 countries and delivering over 3 billion minutes of voice chat a month, the Vivox Network claims to be the world's largest voice network for gamers.

**BACK THEN**, in the early 1990s, modems crawled along with just 14.4-kilobit-per-second bandwidth, and the 386 and 486 processors in desktop PCs weren't powerful enough to compress the traffic efficiently. So VocalTec got to work again, developing a technology to squeeze the data into a 10-kb/s channel, leaving CPU power available for other applications. "That's when we thought, now we can put this on the Internet," Cohen says.

In 1995, VocalTec launched the world's first commercial voice over Internet Protocol (VoIP) application. "You could just download it; you didn't need to buy any hardware," Cohen says.

"Then suddenly it all became clear. All the technologies we created initially, to deal with packet loss and jitter, all that was needed to make this work. Without these, it would not work at all."

The service was still rather rudimentary: You could use your PC to call someone only if that person subscribed to the same VoIP service as you—in this case, VocalTec's Internet Phone, or iPhone, service. There was no interoperability between the various VoIP providers. Other VoIP providers were out of bounds, as was anybody using a standard phone service. If a VoIP provider wanted to connect calls between, say, the United States and Brazil, it had to set up hardware in both markets.

To get around the problem, in 1997 VocalTec and Daniel Berninger, an American entrepreneur who'd worked with AT&T, established a global VoIP exchange called ITXC. This scheme effectively stuck the Internet in the middle of a long-distance call: Because any VoIP service provider could connect to ITXC, a subscriber to one VoIP service could call someone in any other service. Also, and more significantly, standard, public switched telephone networks could also connect to ITXC, so a subscriber to a VoIP service could at last call somebody in the regular phone network with relative ease. ITXC brokered all the interconnect deals between VoIP providers

worldwide, giving them greater reach, and made similar deals with standard telecom players so the VoIP start-ups didn't have to. In one stroke, ITXC pushed VoIP on its way to becoming a bona fide alternative to the public switched network.

ITXC was the model for Vonage Holdings Corp., in Holmdel, N.J., a company Berninger later helped found as the first consumer VoIP service provider. It signed up its first residential subscriber in March 2002, a full year ahead of Skype's beta debut.

**MEANWHILE**, in the background, more technical challenges were appearing. Throughout the world, broadband was exploding, cable and digital subscriber line (DSL) connections were becoming commonplace, and people were getting comfortable with having wireless routers in their homes. A VoIP application now had to get past a router's firewall as well as any other software firewalls a user might deploy against viruses; it was a difficult task to perform without an IT professional easily at hand.

Next, VoIP had to jump the hurdle posed by network address translation. NAT accounts for the fact that devices on the home network—laptops, PCs, Wi-Fi routers, and VoIP handsets—are invisible to the outside Internet. In essence, NAT substitutes a different IP address for the original addresses assigned when the data packet leaves its origin. So, while Vonage and

## HONORABLE MENTION

## Tablets

*The New Computing Covenant*

Apple brings tablets down from the mountain

In his 1972 article "A Personal Computer for Children of All Ages," computer scientist Alan Kay imagined the DynaBook, then a computer of "science fiction," around 2 centimeters thick, weighing less than 2 kilograms, and the size and shape of a paper notebook, with a power-charging connection for use at work or in libraries. Arguably, the first machines even to resemble Kay's tablet device emerged in the 1980s, as digital clipboards for insurance adjusters and salespeople.



Then, in April 2010, Apple released the iPad. Only 1.34 cm thick, the Wi-Fi-enabled and 3G-capable model weighs just 0.73 kg. Apple sold some 2 million units in 60 days and 3 million in 80 days. Meanwhile, HP, Dell, Samsung, Notion Ink, Asus, and Lenovo, among others, all have similar tablet computers on the market or are planning them.

According to Jeff Hawkins, developer of the 1989 GridPad, an early tablet, and later of the Palm Pilot, the consumer versions had to wait for flat color displays, low-power CPUs, better batteries, and wireless networks. "The technology didn't exist 20 years ago that was necessary for successful consumer tablets," he says.

Still, Kay says, tablet computers haven't yet reached his vision of the DynaBook. "What end users can make, and what it takes to make something, are both woefully inadequate on today's machines," he says. With a different approach, he adds, tablets such as the iPad could be "one of the greatest educational amplifiers for children ever made."

—Joseph Calamia

## BET YOU DIDN'T KNOW

In 1995, VocalTec launched the world's first commercial VoIP application. The downloadable app was called Internet Phone, or iPhone for short.

most of its competitors got bogged down in disputes over setting standards for traversing the firewall and NAT, Skype secured itself a commanding lead in the burgeoning market by bypassing the standards, relying instead on its own technology.

The founders of Skype, Niklas Zennström and Janus Friis, managed to solve these problems with the peer-to-peer technology they had pioneered at Kazaa Media Desktop. Their technology employed decentralized routing, in which every node—in this case, a subscriber's PC—uses an encrypted channel to keep track of all other users and resources in the network, sort of like opening a tunnel through the firewall and NAT barrier. Wideband codecs—compression systems that capture a wide range of frequencies—enabled Skype to deliver better audio than a fixed-line telephone could manage.

The service caught on fast. In September 2005, Zennström and Friis sold the company to eBay for US \$2.5 billion. Zennström, Friis, Berninger, Cohen, and Haramaty were part of a new breed: twentysomethings with the vision and technical brilliance to overturn the established order. Another member of that club was Mark Spencer, who had started up Digium, in Huntsville, Ala., a company that provided Linux tech support, while he was still a computer engineering student at Auburn University.

Spencer balked at paying tens of thousands of dollars for a telephone system—that is, a PBX, or private branch exchange—for his start-up company, so he wrote his own software-based switchboard. He called the software Asterisk, after the Unix symbol for “everything.” It was only a few years later, in the early 2000s, that it dawned on him that people were more interested in the phone system than in the tech support service.

For the traditional telephone companies, this was the second blow of the old one-two punch: First they'd had some of their business siphoned off by VocalTec and ITXC; now Digium's open-source software was cutting the cost of equipping a telco in the first place. Now pretty much anybody could set up shop as a VoIP provider.

“Telecom products were really expensive, and there was a real need for customization, especially in other countries [outside the United States],” Spencer recalls. “All these things lined up just right, so that when Asterisk came out, it was able to win a lot of attention.”

IN 1932, AT&T's bean counters had the first and last word on telephonic voice quality: They said they wanted the worst quality that paying customers would tolerate. So Bell Telephone Laboratories engineer Harvey Fletcher (who would later invent an electronic hearing aid) truncated the high and low frequencies—below

300 hertz and above 3300 Hz—in the process removing subtlety and emotion from telephonic voices. Fletcher's legacy continues in all the real telephony networks in the world, and it's not the only throwback. In the 15 years since Cohen and his peers decided to take on the telecom giants on their own turf, the user experience has hardly changed. A phone call is much the same as it was in 1994. Only the price has fallen—and not fast enough to prevent other communications media, like e-mail and instant messaging, from squeezing out voice. For voice to get back in the game, Berninger argues, it must offer more.

It could, above all, offer better voice quality. Today's networks can do the job because they're far more advanced than the ones that carried Cohen's first croaking attempts at packetized telephony. According to Skype's chief technology officer, Jonathan Rosenberg, the highest-quality voice calls last around 31 minutes on average, compared with 21 minutes for the low-quality ones. This phenomenon is forcing the traditional telcos to fall in line and adopt VoIP themselves. Operators can no longer get away with the attitude of “if it ain't broke, don't fix it.”

Ironically, for a technology that started life with a dependency on wires, nowhere is the evolution of voice services happening at a faster pace than in the wireless world. Mobile phone connections

are racing past the 5 billion mark worldwide, and the telco community is consolidating on a common IP-based platform for the fourth generation (4G) of mobile telephony, LTE (Long Term Evolution), in which VoIP is no longer an option—it's a requirement.

According to Eric Ericsson, head of telephony evolution at telephony equipment vendor Ericsson, the mobile industry's Voice over LTE initiative will allow carriers to deliver better service than Skype and its ilk at a lower cost than can be managed today. It also is supposed to make it easier to add new features, such as cheaper roaming, video, and “presence,” which routes the call to the device that's most convenient for the user at the moment.

To be sure, a complete switchover to VoIP or LTE won't happen overnight. Operators have invested too much in their legacy voice networks to kill them off in favor of what is still seen as an unproven technology. Though 4G services are being launched right now, they'll coexist with 3G and even 2G for much of the next decade.

But as communications adopt an all-IP architecture, it will get easier to overlay voice on top of other technologies. Digitized voice is finding its way into dozens of applications, including social networking, online gaming, videoconferencing, even advertising. Voice will be reduced to a commodity, like electricity or water. A good thing, too.

—JAMES MIDDLETON

# NO. 4 LED Lighting

**BLUE + YELLOW = WHITE**

**Giving LEDs the blues was the key to replacing the incandescent bulb**

BACK IN THE 20th century, just about the only LED you normally saw was the one that lit up when your stereo was on. By the noughties, tiny light-emitting diodes were also illuminating the display and keypads of your mobile phone. Now they are backlighting your netbook screen, and soon they'll replace the incandescent and compact fluorescent lightbulbs in your home.

This revolution in lighting comes from the ever-greater bang the LED delivers per buck. With every decade since 1970, when the red LEDs hit their stride, they have gotten 20 times as bright and 90 percent cheaper per watt; the relation is known as Haitz's Law, and it applies also to yellow and blue LEDs, which were commercialized much later.

The forerunners of the white LEDs that are now going into lightbulbs were the chips that backlit handsets starting about a decade ago. Back then, they used tens of milliamps and consumed a watt for every 10 lumens of light they produced. They were also tiny—just 300 micrometers on a side.



Since then, the chips have more than tripled in size, to a millimeter square or more, current has shot up to an ampere or so, and efficiency has rocketed to around 100 lm/W. They now have everything they need to dominate lighting, except for a low enough price. But that, too, will soon come.

Even now, white LEDs are competitive wherever

replacing a burned-out lamp is inconvenient, such as in the high ceilings and twisty staircases of Buckingham Palace, because LEDs last 25 times as long as Edison's bulbs. They have a 150 percent edge in longevity over compact fluorescent lights, and unlike CFLs, LEDs contain no toxic mercury. That means it isn't a pain to dispose of them,

and you don't have to worry that your house has become a hazard zone if one breaks.

Making these white-emitting chips bigger and driving them harder has been quite easy; it was increasing the efficiency that required a radical redesign of the device's architecture. To produce the first generation of white LEDs, engineers would deposit a stack of carefully chosen gallium nitride and indium gallium nitride layers on a semitransparent substrate to yield blue-emitting devices; then they'd add a yellow-emitting phosphor on top to turn the output white. However, this design traps a lot of light within the chip and sends another fraction in the wrong direction, through the substrate.

To address both weaknesses, engineers coated the nitride film—a combination of GaN and InGaN layers—with a metal that acts as a mirror, then flipped the assembly over, removed the substrate, and roughened the underlying surface. In the resulting chip, because most of the rays impinge on the textured

## COMPANY TO WATCH: SORAA, FREMONT, CALIF.

Soraa, a California-based university spin-off cofounded by LED trailblazer Shuji Nakamura, is pioneering a different approach to making gallium nitride devices. By making light-emitting chips on a different cut of the GaN crystal, it can build brighter devices, free from the strong internal electric fields that hamper light emission.

top surface at a shallow enough angle to avoid reflecting back, nearly all the light can get through to the world outside.

Europe's leading LED manufacturer, Osram Opto Semiconductors, in Germany, and the two U.S. LED giants Cree and Philips Lumileds are all using variations of this approach. Japan's Nichia, the world's biggest LED manufacturer, has a different way of doing things. Its engineers also roughen the top surface, but they do this by etching a hexagonal pattern into the substrate, which they do not subsequently remove from the gallium nitride film.

These second-generation white LEDs hit the market three or four years ago. Since then interest has rocketed: "If you go to any [lighting] show now, they might as well be called the LED show," says Rick Hamburger, director of segment lighting at Philips Lumileds.

Commercial success followed. White LEDs now illuminate parking lots, streets, and civic buildings. Exactly when they make it into most homes will depend on the price. I just bought a really high-quality, warm-white LED bulb in the United Kingdom from Philips for about US \$55; my lamp consumes just 7W while emitting as much light as a 40-W incandescent. (Products that give off a harsher, bluetinted light go for as little as \$10.) I calculate that if I use it for 4 or 5 hours a day, it should pay for replacing the incandescent bulb in about five years.

The manufacturing cost should fall as production yields rise and substrates grow. "At the moment, one-third of the LEDs in the world are made on 2-inch wafers," says Mark McClellan, who directs new business development at Cree. Toolmakers are now offering equipment for 3-inch, 4-inch, and even 6-inch substrates, and Cree plans to start using the largest of these platforms in the next 18 months.

Another way to drive down the cost is to increase the light output at a particular current. That's one of the goals of the U.S. Department of Energy's 2010 solid-state lighting road map, which calls

#### BET YOU DON'T KNOW

LEDs glow brighter if you put them in the fridge. Wal-Mart has cottoned on to this, and since 2006 it has been ripping the fluorescent tubes out of its refrigerators and putting white LEDs in their place.

for more than doubling the lumens per watt in commercial LED products by 2015. Or engineers could try to build better packages for handling additional heat so they could crank the current up higher and get more light out of each LED.

Of course, LEDs give us much more than just a more efficient, longer-lasting bulb. They're small, cool in operation, and easy to place in walls, automobiles, appliances, even the heels of children's shoes. When designers fully exploit their potential, LEDs will light up places we'd never thought to use them, thus changing the look of our world.

With price the only remaining hurdle and falling all the time, it's clear that this technology will be a winner in the long run. The one potential casualty that no one is talking about: jokes about changing the lightbulb, which may be heading the way of the dodo.

—RICHARD STEVENSON

#### HONORABLE MENTION

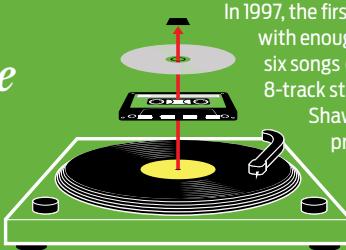
## MP3

### Compress Me a Song

A German researcher took us from albums to algorithms

When my children are my age, they will surely look back with bemusement at the crude means by which their elders entertained themselves. They'll laugh at the thought of vinyl platters spinning like carousels, cartridges containing spools of magnetic tape, and even laser-etched metal sheets embedded in plastic discs. They'll take for granted that you can carry every bit of music you own in your pocket.

And it's no sweat now, because NAND flash memory sells for about a dollar per gigabyte. But back in 1989, when a German researcher introduced the idea behind the MP3 compression algorithm, flash memory cost several hundred



dollars per megabyte. Several things happened at the close of the last decade that together marked the dividing line between B.C. (before compression) and A.D. (Apple domination).

In 1997, the first MP3 player was introduced, with enough storage capacity for about six songs (paltry, it's true, even by 8-track standards). Two years later, Shawn Fanning rolled out Napster, providing an easy way for people with MP3 files to share the songs in their collections. Around that same time, the first USB flash memory key drives arrived, further

stoking demand for nonvolatile memory.

In 2001, when Apple introduced the first iPod, consumers' expectations were irrevocably changed. (Pay for music online? Perhaps. Buy a whole LP? Fuhgeddaboutit.) By 2006, digital music had unseated its predecessors: Five billion digital music files were swapped on peer-to-peer networks that year, and the ubiquitous iPod, aided by Apple's iTunes online music store, was fast approaching 100 million units a year in sales.

Think: When was the last time you even saw someone carrying a portable CD or cassette player or found yourself browsing the shelves in a record store?

—Willie D. Jones

NO. 5

# Multicore CPUs

## PROCESSOR PROLIFERATION

**From multicore to many-core to hard-to-describe-in-a-single-word core**

BACK IN 1994, programmers figured that whatever code they wrote would run at least 50 percent faster on a 1995 machine and 50 percent faster still on a '96 system. Coding would continue as it always had, with instructions designed to be executed one after the other.

But Kunle Olukotun, then a newly minted professor of electrical engineering at Stanford, saw that the party couldn't go on forever. The microprocessors of the day couldn't scale up as efficiently as you'd expect through the mere addition of ever more and ever faster transistors, the two things that Moore's Law provided.

To solve that problem, Olukotun and his students designed the first general-purpose multicore CPU. This idea, more than any other in the past decade, is what has kept the semiconductor industry climbing the Moore's Law performance curve. Without multicore chips, the computing capability



of everything from servers to netbooks would not be much better than it was a decade ago. Everyone's happy—except perhaps for the programmers, who must now write code with threads of instructions that must be executed together—in pairs, quartets, or even larger groupings.

It's not that old, single-core CPUs weren't already doing some parallel processing. When Olukotun began his work, most microprocessors had a "superscalar" architecture. In the superscalar scheme, the CPU contained many replicated components, such as arithmetic units.

Individual instructions would be parceled out to the waiting components. Scaling up such "instruction-level parallelism" meant building in more and more such components as the years rolled by.

Olukotun argued that within a few more generations, it wasn't going to be worth the effort. You needed to provide a quadratic increase in resources for a linear increase in performance, he said, because of the complexity of the logic involved in parceling out and keeping track of all the instructions. If you combined that with the delays inherent in the mess

of interconnects among all those parts, it seemed a losing proposition. Doug Burger and Stephen Keckler, both computer scientists at the University of Texas, Austin, put a finer point on it later in the decade, calculating that instead of the 50 percent improvements everyone had gotten used to, the computing industry should start thinking 12.5 percent. And 12.5 percent isn't much of a reason to buy a new computer, is it?

Olukotun's answer was Hydra, a processor whose parallelism came not from redundant circuits within a single complex CPU but from building four copies of a simpler CPU core on one chip. That way, you save on interconnects and on the time lost casting instructions out and reeling answers back in. In Hydra, you got parallel processing without all the delay-inducing complexity. In 1998 "we wrapped up the hardware portion of the project and declared victory," says Olukotun.

It was a quiet victory. In the computing environment of the 1990s, Hydra seemed a little crazy, Olukotun says. Superscalar designs were still delivering 50 percent performance improvements every year. "It was by no means clear at the time that our view of the world was going to win," he recalls. And indeed it would be years before processor giants like Intel, Advanced Micro Devices, and IBM got the multicore religion Olukotun preached. And when they did, it would largely be for a reason he had hardly considered: power.

## COMPANY TO WATCH: TILER CORP., SAN JOSE, CALIF.

In 2008, MIT professor Anant Agarwal transformed an academic project to efficiently make use of lots of simple cores connected in a mesh into Tilera, a company whose commercial processor has one of the highest core counts of all. It's selling a 64-core product now, the 100-core Tile-Gx starts sample shipments in mid-2011, and the company plans a 200-core product in 2013.

It turned out that the rising density of transistors on a chip intensified the hot spots in CPUs. This, even more than the resource-to-performance ratio that had bothered Olukotun, was the problem that seemed most likely to stop Moore's Law in its tracks. In presentations in 1999 and later, Intel engineers showed that if trends in microprocessors were to continue, by 2010 they'd burn as hot as the surface of the sun.

The answer was clear: Slow down the CPU's clock and add more cores. That way, you'd gain more from the extra parallelism than you lost from the slower processing. The chip would gobble less power and generate less heat.

It was a daunting engineering job, but the big processor makers were more prepared than you might expect, because they'd already redesigned the way that CPUs communicate with other chips. For Intel, the solution, called the front-side bus, debuted in 1996, in the Pentium Pro. According to Intel senior fellow Steve Pawlowski, the bus was, in large part, originally meant to save on testing and validation costs. It was a very convenient piece of luck, because when the time came to get two cores working together, the front-side bus was there, waiting to link them up. And in 2005 Intel released its first dual-core component, the Pentium D, which was really two single-core chips in the same package, tied together by the front-side bus.

Engineers at AMD— influenced by Olukotun,

Burger, and Keckler— were more purposeful. They prepped the initial, single-core version of AMD's breakout server chip, the Opteron, with a redesigned communications component that would make a multicore version easy. That version came out in 2005. The component was the chip's "northbridge," a switchyard that acts as the chip's gateway to other chips in the computer.

IBM was, arguably, even more on top of the multicore revolution. Around the same time that Intel's Pentium Pro was released, the company began work on its Power4 processor. Looking for an advantage, IBM entertained a number of cutting-edge ways to enhance instruction-level

parallelism in single cores, according to Jim Kahle, chief architect of that design. But, deciding to play it safe, his team rejected each. "Turned out to be a good idea," he says. The most conservative option was a dual-core processor. And so Power4, released in 2001, became the first mainstream computer processor with more than one core on a single die.

Olukotun himself wasn't absent from the revolution he predicted. In 2000, he took the lessons from Hydra and founded Afara Websystems. That start-up was acquired by Sun Microsystems in 2002, and its technology became Sun's powerful Web server CPU, the eight-core UltraSparc T1 (also known as Niagara), released in 2005.

Once the multicore revolution got going, it had a natural momentum. "As soon as we got to two cores, it became obvious we needed to start thinking about going to four," says AMD corporate fellow Chuck Moore. "And as soon as we got to four, we started thinking about going to six or eight."

So today programmers can again count on a solid 50 percent annual gain in effective processing power, driven not by raw speed but by increasing parallelism. Therein lies the rub. Back when Olukotun worked out Hydra, "it was unclear if you could take advantage of all the parallelism," he says. "It's still unclear today."

So where does it end? Sixty-four cores? Already there. Start-up Tilera Corp.

## HONORABLE MENTION

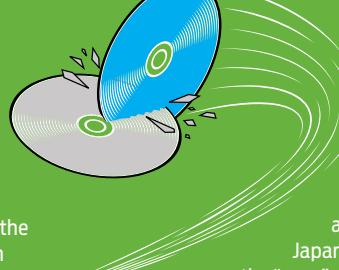
# DVDs

## Time to Eject The rise and fall of the optical disc

This year *Star Wars* fans will have the chance to buy yet another version of the films, this time on high-definition Blu-ray. Although the new disc may shoulder aside the DVD, it cannot equal it as a game changer.

Take for example Netflix, the movie rental company. It owes its existence to the DVD, because this disc, unlike the VHS tape, was not too expensive to ship. Now, Netflix typically mails 2 million DVDs a day, says Steve Swasey, vice president of corporate communications. When cofounder Reed Hastings first imagined movies by mail in the 1990s, DVDs were so new that he didn't own any. He tested the system by mailing CDs to himself.

Blu-ray required lasers capable of creating



and reading smaller marks—stamped pits, dye discolorations, or quenched metal coatings—on the surface of a disc. A DVD uses the red beam of a 650-nanometer laser; a Blu-ray uses a blue 405-nm beam. Shuji Nakamura developed the laser diode required for Blu-ray while working at Nichia Corp., in Tokushima, Japan. He says he chose to study

the "poor" semiconductor gallium nitride to make laser diodes in the 1980s because he wanted opportunities to publish. "The major companies were using zinc selenide. There were too many papers," Nakamura says.

Making more marks in even more layers might lead to future generations of optical discs, says Barry Schechtman, executive director emeritus at the Information Storage Industry Consortium. But he wonders whether the disc is already coming to the end of its momentous life, given external hard drives, flash drives, and streaming. "When we will need another generation beyond Blu-ray—and even if we would need it—is still a big question," he says.

—Joseph Calamia

## "Cores are the new transistors"

KUNLE OLUKOTUN, STANFORD UNIVERSITY

is selling it (see "Company to Watch"). Two hundred? One thousand? "Cores are the new transistors," jokes Olukotun.

Just adding traditional cores isn't going to be enough, says AMD's Moore. The scheme may have saved the power-versus-performance curve for a time, but it won't do so forever. "These days, each core is only getting 8 or 10 watts," he says. "In some sense we're running back into that power wall." With its new Bulldozer architecture, AMD has managed to buy some breathing room by finding a set of components that the cores can share without seriously degrading their speed. But even so, Moore's best guess is that 16 cores might be the practical limit for mainstream chips.

Intel's Pawlowski won't put a number on it, but he will say that memory bandwidth between the cores is likely to be the big constraint on growth.

What will keep computing marching forward, according to Moore, is the integration of CPUs and graphics processing units (GPUs) into what AMD calls an accelerated processing unit, or APU. Say you want to brighten an image: Just add 1 to the number representing the brightness of every pixel. It'd be a waste of time to funnel all those bits single file through a CPU core, or even 16 of them, but GPUs have dedicated hardware that can transform all that data practically at once.

It turns out that many modern workloads have just that kind of data-level parallelism. Basically, you

want to do the same thing to a whole lot of data.

That key insight drove AMD to acquire a leading GPU maker, ATI Technologies, and start work on jamming their two products together. So a future processor, from AMD at least, would probably contain multiple CPU cores connected to several GPU elements that would step in whenever the work is of a type that would gum up a CPU core.

With Cell, the processor released in 2006 to power the PlayStation 3, IBM has already gone in that direction. Instead of actual GPU functions, it developed a more flexible core that specializes in executing the same instruction on several pieces of data at once. IBM, with help from Toshiba and Sony, stuck eight of the new cores on the same chip with a more traditional processor core. But that's not quite where Kahle, who led the Cell project, sees things going in the future. Instead he expects to see a mix of general-purpose cores and cores specialized for one task—encryption, decryption, video encoding, decompression, anything with a well-defined standard.

Olukotun agrees that such a heterogeneous mix of cores is the way forward, but it's not going to be easy. "It's going to make the programming problem much worse than it is today," he says. "Just as things were getting bad for software developers, they have the potential to get worse." But don't worry. They're working on it.

—SAMUEL K. MOORE





# Cloud Computing

## IT'S ALWAYS SUNNY IN THE CLOUD

**Cloud computing puts your desktop wherever you want it**

JUST 18 YEARS ago the Internet was in its infancy, a mere playground for tech-savvy frontiersmen who knew how to search a directory and FTP a file. Then in 1993 it hit puberty, when the Web's graphical browsers and clickable hyperlinks began to attract a wider audience. Finally, in the 2000s, it came of age, with blogs, tweets, and social networking dizzying billions of ever more naive users with relentless waves of information, entertainment, and gossip.

This, the adulthood of the Internet, has come about for many reasons, all of them supporting a single conceptual advance: We've cut clean through the barrier between hardware and software. And it's deeply personal. Videos of our most embarrassing moments, e-mails detailing our deepest heartaches, and every digit of our bank accounts, social security numbers, and credit cards are splintered into thousands of servers controlled by dozens—hundreds?—of companies.

Welcome to cloud computing. We've been

catapulted into this nebulous state by the powerful convergence of widespread broadband access, the profusion of mobile devices enabling near-constant Internet connectivity, and hundreds of innovations that have made data centers much easier to build and run. For most of us, physical storage may well become obsolete in the next few years. We can now run intensive computing tasks on someone else's servers cheaply, or even for free. If this all sounds a lot like time-sharing on a mainframe, you're right. But this time it's accessible to all, and it's more than a little addictive.

The seduction of the business world began first, in 2000, when Salesforce.com started hosting software for interacting with customers that a client could rebrand as its own. Customers' personal details, of course, went straight into Salesforce's databases. Since then, hundreds of companies have turned their old physical products into virtual services or invented new ones by harnessing the potential of cloud computing.

### FUN FACT:

Transmitting a terabyte of data from Boston to San Francisco can take a week. So the impatient are returning to an old idea, "Sneakernet": Put your data on a disc, take it to FedEx, and get it to a data center in a day.

FRANK CHIMERO

Consumers were tempted four years later, when Google offered them their gateway drug: Gmail, a free online e-mail service with unprecedented amounts of storage space. The bargain had Faustian overtones—store your e-mail with us for free, and in exchange we'll unleash creepy bots to scan your prose—but the illusion of infinite storage proved too thoroughly entralling. This was Google, after all: big, brawny, able to warp space and time.

#### COMPANY TO WATCH: F-SECURE, HELSINKI, FINLAND

F-Secure Corp. uses the cloud to protect the cloud. Its global network of servers detects malicious software and distributes protective updates in minutes. To assess a threat, it uses the Internet itself: A widely available application is more likely to be safe than a unique file.

**GMAIL'S INFINITE**  
storage was a start. But the program's developers also made use of a handy new feature. Now they could roll out updates whenever they pleased, guaranteeing that Gmail

users were all in sync without having to visit a Web site to download and install an update. The same principle applied to the collaborative editing tools of Google Docs, which moved users' documents

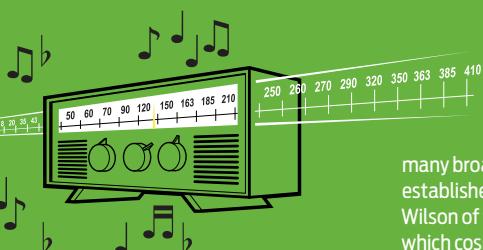
into the browser with no need for backups to a hard drive. "Six years ago"—before the launch of Docs—"office productivity on the Web wasn't even an idea," recalls Rajen Sheth, a product manager at Google.

Docs thus took a first, tentative bite out of such package software products as Microsoft Office. Soon hundreds of companies were nibbling away.

Adding new features and fixing glitches, it turned out, could be a fluid and invisible process. Indeed, sites like the photo storage service Flickr and the blog platform WordPress continually seep out new products, features, and fixes. Scraping software off individual hard drives and running it in anonymous data centers obliterated the old, plodding cycles of product releases and patches.

In 2008, Google took a step back from software and launched App Engine. For next to nothing, Google now lets its users upload Java or Python code that is then modified to run swiftly on any desired number of machines. Anyone with a zany idea for a Web application could test it out on Google's servers with minimal financial risk. Let's say your Web app explodes in popularity: App Engine will sense the spike and swiftly increase your computing ration.

With App Engine, Google began dabbling in a space already dominated by another massive player, Amazon.com. No longer the placid bookstore most customers may have



#### HONORABLE MENTION

## HD Radio

### *The End of Analog*

#### AM and FM go HD

In 2002, HD Radio promised Americans FM-quality sound on AM channels and CD-quality sound on FM channels—with no subscription charge. In 2006, retailers sold 28 000 HD Radio receivers for nightstands and dashboards, reports iBiquity Digital Corp., the Columbia, Md., company that developed the system. In the first three quarters of 2010, sales hit 1.2 million. Radio was finally going digital.

Well, almost digital. Called IBOC for in-band on-channel, today's "hybrid" setup requires broadcasters to continue transmitting the old analog signal. Upgrading to the iBiquity system allows them also to transmit a digital signal, centered on the analog channel and in the frequencies slightly above and below. For FM channels, that's about 101 to 200 kilohertz from the analog center. To avoid interference,

broadcasters transmit these digital signals at a lower power than their analog neighbors.

The IBOC system appeals to many broadcasters because it keeps intact their established territories and frequencies, says Dave Wilson of the Consumer Electronics Association, which cosponsors the National Radio Systems Committee, one of the organizations that tested the system. It also takes up no more of the radio spectrum than did the old analog system.

The original point of going digital was to get improved sound quality, but ambitions grew along with the technology. Because today's compression programs can stuff far more information into a given bandwidth than had been dreamed possible, new things are being found to stuff: captioning for the deaf, iTunes song "tagging," album art, and even "multicasting"—different broadcasts layered into one station, found by tuning a bit above and below the center FM channel. The system is also more efficient than streaming Internet or satellite services, says Robert J. Struble, president and CEO of iBiquity. It takes only one tower on the top of the Empire State Building, he notes, to dole out HD Radio to all of New York City.

To upgrade, broadcasters must buy new transmitting equipment and pay a fee to iBiquity, but the company reports that over 2000 U.S. stations have made the switch. "They feel this is a question of survival," says Ann Gallagher at the Federal Communications Commission, audio division, regarding a 2010 broadcasters' panel discussion. "Radio doesn't want to be the last analog medium."

—Joseph Calamia

assumed it to be, in 2000 Amazon had begun to use its sales platform to host the Web sites of other companies, such as the budget retailer Target. In 2006 came rentable data storage, followed by a smorgasbord of “instances,” essentially slices of a server available in dozens of shapes and sizes. (Not satisfied? Fine: The CPU of an instance, which Amazon calls a compute unit, is equivalent to that of a 1.0- to 1.2-gigahertz 2007 Opteron or 2007 Xeon processor.)

To get a flavor of the options, for as little as about US \$0.03 an hour, you can bid on unused instances in Amazon’s cloud. As long as your bid exceeds a price set by Amazon, that spare capacity is yours. At the higher end, around \$2.28 per hour can get you a “quadruple extra large” instance with 68 gigabytes of memory, 1690 GB of storage, and a veritable bounty of 26 compute units.

In a sense, the cloud environment makes it easier to just get things done. The price of running 10 servers for 1000 hours is identical to running 1000 machines for 10 hours—a flexibility that doesn’t exist in most corporate server rooms. “These are unglamorous, heavy-lifting tasks that are the price of admission for doing what your customers value,” says Adam Selipsky, a vice president at Amazon Web Services.

As unglamorous as an electric utility, some might say. Indeed, Amazon’s cloud services are as close as we’ve gotten to



### WIZARDS OF AN ONLINE OZ

The Internet may sometimes seem like a massive astral projection, but it, too, must have its little men behind curtains, operating the gears and levers of the great and powerful cloud.

Not just Google and Amazon, but Microsoft, Rackspace, SGI [above], and many other companies have used striking economies of scale to acquire cheap commodity hardware and build sprawling, multihectare server farms. James Hamilton, a vice president and distinguished engineer at Amazon, once estimated that data centers with tens of thousands of computers could use their clout to buy hardware and network bandwidth for one-seventh the price a piddling 1000-server facility could exact.

“Twitter, Facebook, Google—their performance needs rise astronomically every day,” notes Michael Coté, a cloud computing analyst at RedMonk, an IT consulting firm. To keep up, companies now buy servers by the shipping container with all the power and networking connections preconfigured. An IT manager plugs the container into a power supply, a network connection, and a cold water tap, and presto, 1400-odd more servers come online.

Now a data center can materialize overnight. Furthermore, the closed environment of a can turns out to be well suited to maintaining exquisite control over airflow for cooling—a major issue in the blazing hot environment of a data center. Following the typical architecture of alternating “hot aisles” full of server racks and “cold aisles” for ventilation, vents blow air in a loop through each container while radiators release heat into “cold” aisles chilled to a brow-mopping 32 °C. —Sandra Upson

the 50-year-old dream of “utility computing,” in which processing is treated like power. Users pay for what they use and don’t install their own generating capacity. The idea of every company running its own generators seems ludicrous, and some would argue that computing should be viewed the same way.

Selling instances, of course, is nothing like selling paperbacks, toasters, or DVDs. Where Google’s business model

revolves around collecting the world’s digital assets, Amazon has more of a split personality, one that has led to some odd relationships. To help sell movies, for example, Amazon now streams video on demand, much like companies such as Netflix. Netflix, however, also uses Amazon’s servers to stream its movies. In other words, Amazon’s servers are so cheap and useful that even its competitors can’t stay away. But to

understand what’s truly fueling the addiction to the cloud, you’ll need to glance a bit farther back in time.

IN THE MID-1990S, a handful of computer science graduate students at Stanford University became interested in technologies that IBM had developed in the 1960s and ’70s to let multiple users share a single machine. By the 1980s, when cheap servers and desktop computers began to supplant mainframe computers, those “virtualization” techniques had fallen out of favor.

The students applied some of those dusty old ideas to PCs running Microsoft Windows and Linux. They built what’s called a hypervisor, a layer of software that goes between hardware and other higher-level software structures, deciding which of them will get how much access to CPU, storage, and memory. “We called it Disco—another great idea from the ’70s ready to make a comeback,” recalls Stephen Herrod, who was one of the students.

They realized that virtualization could address many of the problems that had begun to plague the IT industry. For one thing, servers commonly operated at as little as a tenth of their capacity, according to International Data Corp., because key applications each had a dedicated server. It was a way of limiting vulnerabilities because true disaster-proofing was essentially unaffordable.

So the students spawned a start-up, VMware. They started by emulating an

Intel *x86* microprocessor's behavior in software. But those early attempts didn't always work smoothly. "When you mess up an emulation and then run Windows 95 on top of it, you sometimes get funny results," Herrod, now VMware's chief technology officer, recalls. They'd wait an hour for the operating system to boot up, only to see the Windows graphics rendered upside down or all reds displayed as purple. But slowly they figured out how to emulate first the processor, then the video cards and network cards. Finally they had a software version of a PC—a virtual machine.

Next they set out to load multiple virtual machines on one piece of hardware, allowing them to run several operating systems on a single machine. Armed with these techniques, VMware began helping its customers consolidate their data centers on an almost epic scale—shrinking 500 servers down to 20. "You literally go up to a server, suck the brains out of it, and plop it on a virtual machine, with no disruption to how you run the application or what it looks like," Herrod says.

Also useful was an automated process that could switch out the underlying hardware that supported an up-and-running virtual machine, allowing it to move from, say, a Dell machine to an HP server. This was the essence of load balancing—if one server started failing or got too choked up with virtual machines, they

#### FUN FACT:

Dude, where are my bits? In the growing obfuscation of who's responsible for what data, Amazon recently deployed its storefront platform on privacy-challenged Facebook for the first time. The irresistible business case? Selling Pampers diapers.

could move off, eliminating a potential bottleneck.

You might think that the virtual machines would run far more slowly than the underlying hardware, but the engineers solved the problem with a trick that separates mundane from "privileged" computing tasks. When the virtual machines sharing a single server execute routine commands, those computations all run on the bare metal, mixed together with their neighbors' tasks in a computational salad bowl. Only when the virtual machine needs to perform a more confidential task, such as accessing the network, does the processing retreat back into its walled-off software alcove, where the calculating continues, bento-box style.

Those speedy transitions would not have been possible were it not for another key trend—the consolidation of life into an Intel world. Back in virtualization's early days, a major goal was to implement foreign

architectures on whatever hardware was at hand—say, by emulating a Power PC on a Sun Microsystems workstation. Virtualization then had two functions, to silo data and to translate commands for the underlying hardware. With microprocessor architectures standardized around the *x86*, just about any server is now compatible with every other, eliminating the tedious translation step.

VMware no longer has a monopoly on virtualization—a nice open-source option exists as well—but it can take credit for developing much of the master idea. With computers sliced up into anywhere between 5 and 100 flexible, versatile virtual machines, users can claim exactly the computing capacity they need at any given moment. Adding more units or cutting back is simple and immediate. The now-routine tasks of cloning virtual machines and distributing them through multiple data centers make for easy backups. And at a few cents per CPU-hour, cloud computing can be cheap as dirt.

SO WILL ALL computing move into the cloud? Well, not every bit. Some will stay down here, on Earth, where every roofing tile and toothbrush seems fated to have a microprocessor of its own.

But for you and me, the days of disconnecting and holing up with one's hard drive are gone. IT managers, too, will surely see their hardware

babysitting duties continue to shrink. Cloud providers have argued their case well to small-time operations with unimpressive computing needs and university researchers with massive data sets to crunch through. But those vendors still need to convince Fortune 500 companies that cloud computing isn't just for start-ups and biology professors short on cash. They need a few more examples like Netflix to prove that mucking around in the server room is a choice, not a necessity.

And we may just need more assurances that our data will always be safe. Data could migrate across national borders, becoming susceptible to an unfriendly regime's weak human rights laws. A cloud vendor might go out of business, change its pricing, be acquired by an archrival, or get wiped out by a hurricane. To protect themselves, cloud dwellers will want their data to be able to transfer smoothly from cloud to cloud.

Right now, it does not.

The true test of the cloud, then, may emerge in the next generation of court cases, where the murky details of consumer protections and data ownership in a cloud-based world will eventually be hashed out. That's when we'll grasp the repercussions of our new addiction—and when we may finally learn exactly how the dream of the Internet, in which all the world's computers function as one, might also be a nightmare. —SANDRA UPSON

# NO. 7 Drone Aircraft



FRANK CHIMERO

## HOW THE DRONES GOT THEIR STINGERS

### Unmanned aerial vehicles come of age

CRUISING SILENTLY overhead, an unmanned Predator aircraft uses its infrared camera to pinpoint the telltale muzzle flashes from a sniper's rifle. The plane's operators, located half a world away, then unleash a Hellfire missile from under its wing, using a laser mounted beneath the craft's nose to guide the munition into the very window the sniper had been shooting from.

Such missions represent a technological tour de force, but they've played out so often over the past few years that they no longer make headlines. What might be news, though, is just how far back the roots of this stunning 21st-century military technology reach.

The first demonstration of a remotely piloted vehicle took place in May 1898 at the Electrical Exposition in New York City's Madison Square Garden. It was less than a month after the outbreak of the Spanish-American War, which, as history buffs may recall, was sparked by the mysterious explosion and sinking of the U.S.S. *Maine* in Havana harbor. So when

## COMPANY TO WATCH: PRIORIA ROBOTICS, GAINESVILLE, FLA.

Prioria Robotics is building small UAVs that autonomously use video to steer around objects. The ability of UAVs to sense and avoid other aircraft is a prerequisite for flying in civilian airspace, and small smart vehicles, like the ones Prioria is developing, may be the first to do so.

the renowned inventor Nikola Tesla used the exposition to demonstrate his “telautomaton”—a small boat operated remotely by radio—the military significance of his creation must have been obvious.

Or maybe not. Perhaps no one watching Tesla steer and flash the lights of his robotic boat had sufficient imagination to see how valuable pilotless vehicles could be in war. Yet that very year Tesla sent a paper to *The Electrical Engineer* magazine describing how a remotely controlled aircraft could be used as an aerial torpedo. His submission was rejected as too fanciful.

Attitudes, of course, evolved during the 20th century. As early as 1917, the U.S. Navy pursued the development of a pilotless aircraft for use against German U-boats; during the Second World War, Nazi forces filled the skies over Britain with thousands of pulse-jet-powered flying bombs; and Israeli Defense Forces used drones against Syrian forces in Lebanon in 1982. But it was only during the past decade that unmanned aerial vehicles matured into fully controllable and reusable combat aircraft. They have also proliferated, often in miniaturized forms, providing easily deployed eyes in the sky for ground troops.

The relatively late blossoming of these vehicles can be explained, in part, by improvements in the various technologies they rely on. But an increased understanding of their



**SKY EYES:** U.S. Army operators in Iraq prepare a Shadow for catapult launch [top]; a soldier heaves a Raven into the air from the perimeter of a U.S. Marine base in Afghanistan [bottom left]; and an airman at Creech Air Force Base checks over a Predator before flight [bottom right].

CLOCKWISE FROM TOP: U.S. ARMY; ETHAN MILLER/GETTY IMAGES; JOHN MOORE/GETTY IMAGES

utility on the battlefield also accounts for the recent upsurge in their use.

PILOTLESS AIRCRAFT began as preprogrammed drones, evolved into remotely piloted vehicles or unmanned aerial vehicles (UAVs), and are now sometimes called unmanned aircraft systems (UASs), in appreciation of the aircraft's role within a larger collection of complex equipment.

They're most commonly used for reconnaissance

or sustained surveillance. But many UAVs are equipped with lasers that can illuminate a target or even mark it for automatic destruction, using laser-guided weapons launched from other platforms. And some of the larger UAVs carry missiles themselves. At the small end of the spectrum are UAVs that a single soldier can carry around and launch by hand. AeroVironment, a company headquartered in Monrovia, Calif.,

manufactures some of the better-known examples, including the Raven, which is fundamentally similar to the radio-controlled planes that hobbyists fly for fun, although it's much tougher and packs more sophisticated electronic gear.

So, clearly, the wherewithal to construct a small UAV has been around for a long time. Why then has the use of Ravens and other hand-launched UAVs burgeoned only in the last decade?

"The technology definitely matured," says Gabriel Torres, an aeronautical engineer and project manager at AeroVironment. He notes that the Pointer, the 1990s-era predecessor of the Raven, used nickel-cadmium batteries and could remain aloft for only 30 minutes, one-third as long as the lithium ion-powered Raven can. The Pointer's support equipment was also awkwardly bulky for a soldier to carry around. "The ground-control station was like an 80-pound box," says Torres. The craft was also limited by its rudimentary autopilot, which initially relied on an electromechanical compass. "But little by little, the technology improved," says Torres.

Strides in the fabrication of microelectromechanical systems, for example, allowed tiny gyroscopes, accelerometers, and airspeed sensors to be added to the smallest of these vehicles, along with increasingly compact and reliable GPS receivers. "The other thing that changed," says Torres, "was an appreciation of the kind of mission that could be fulfilled with this type of system." With the Raven, he explains, U.S. military planners were able to work out detailed tactics, techniques, and procedures for soldiers to use small aerial vehicles in combat. "This all became very important in 2000 and 2001," he says.

This period was also a turning point for larger UAVs, in part because of advances in computers and radio links. The more

important reason to call 2001 a watershed year, however, is that it marked the very first time anyone put weapons on a reusable unmanned aircraft.

**WHEN GENERAL ATOMICS** Aeronautical Systems developed the Predator in the mid-1990s, it was intended solely for surveillance. Plans took a sharp turn, though, during one of its early military deployments, with NATO forces over Kosovo.

That's when Gen. John P. Jumper, commander of U.S. Air Forces in Europe, noticed what he called "the dialogue of the deaf." Predator operators would identify a target, say, an enemy tank lurking between buildings, and then try to guide the pilot of an attack aircraft to it by radioing verbal instructions. More often than not, this just caused a lot of confusion.

So Jumper had the Predators outfitted with laser designators, which could automatically guide missiles or artillery shells to their targets. He later pushed for the Predator to carry its own weapons, and the first instances of this UAV using air-to-surface missiles took place not long after, in the hunt for al-Qaeda members in Afghanistan in October 2001.

The following year saw the Predator's role expand to ground support, when it destroyed a machine gun bunker that had pinned down U.S. Army rangers in Afghanistan. And for the first time, a Predator fired a Stinger air-to-air missile in action, at an Iraqi fighter.

#### BET YOU DON'T KNOW

On 2 August 2010, one of the U.S. Navy's unmanned Fire Scout helicopters lost communication with operators and was fast approaching Washington, D.C., before it was brought under control.

That same year technical refinements allowed operation of a Predator to be shifted from one ground control station to another, so that UAV pilots located in combat areas could pass control to comrades stationed at U.S. bases. This is how the U.S. Air Force operates its UAVs, using pilots and crews deployed overseas to launch and recover the aircraft, while pilots at Creech Air Force Base in Nevada manage the intervening part of the missions.

This approach is decidedly different from the way the U.S. Army handles its fleet of more than 4000 UAVs, including the biggest one it flies, known as the Gray Eagle, which can carry four Hellfire missiles and looks something like a Predator on steroids.

For one, all Army UAS operators work alongside combat troops, even for vehicles that are capable of being flown over satellite links from anywhere on the globe. Also, unlike the Air Force, the Army hasn't restricted itself to using officers with piloting experience to operate its UAVs.

The Air Force initially put just seasoned aviators in that role, although it has more recently started using men and women who have spent only a few tens of hours in the cockpit—about what it would take to get a private pilot's license—to fly its UAVs. The Army, however, trains people who have never flown regular aircraft for that job.

"We recruit folks coming out of high school," says Lt. Col. Patrick Sullivan, commander of the Army's unmanned aircraft systems training battalion, located at Fort Huachuca in southeast Arizona. "We have soldiers that just came from basic training. They come to Fort Huachuca, and we train them to be UAS operators."

Army Col. Robert Sova, training and doctrine command capability manager for UAS, confirms that this approach extends throughout the Army.

"Everything from our smallest systems to our largest are flown by enlisted operators," says Sova. "They don't have a pilot's license—they are not pilots. That's why we're adamant about calling them 'operators.' We have no intention of having pilots flying our unmanned aircraft."

The Army's stance on this point reflects that service's particular history and culture. But it also reflects the evolution of UAS technology. During the 1980s and 1990s, operating such an aircraft indeed required someone with considerable training and good eye-muscle coordination. It might even require two of them. The

"external pilot" would handle the takeoff and landing by looking directly at the plane, while the "internal pilot" would manage operations for the bulk of the flight.

Steve Reid is vice president of unmanned aircraft systems at AAI Corp., the Hunt Valley, Md., company that makes the Shadow, a 3.4-meter-long UAV that the U.S. Army adopted for tactical use in late 1999. He explains that in 2001 and 2002, AAI added special radio equipment to allow the Shadow to make automated landings. Although engineering such capability was a considerable challenge, it relieved the Army of having to train pilots in the tricky skills needed to land these planes by eye. What's more, the automation works better. "I can tell you great stories of sandstorms rolling into Iraq—blinding sandstorms, where you can't see any aircraft out there—and Shadows land right where they are supposed to," says Reid.

Army Sgt. 1st Class Kelly Boehning, a Gray Eagle operator stationed at Fort Huachuca, has similar praise for his craft's automated landing system. "It lands perfectly, every time, without exception," says Boehning. "It takes some of the fun out, not having the stick and rudder, but it also takes the pilot error out: We don't have any incidents landing—that's where Predator's downfall is."

AUTOMATION IS INDEED a strong theme in the Army's recently published Unmanned Aircraft

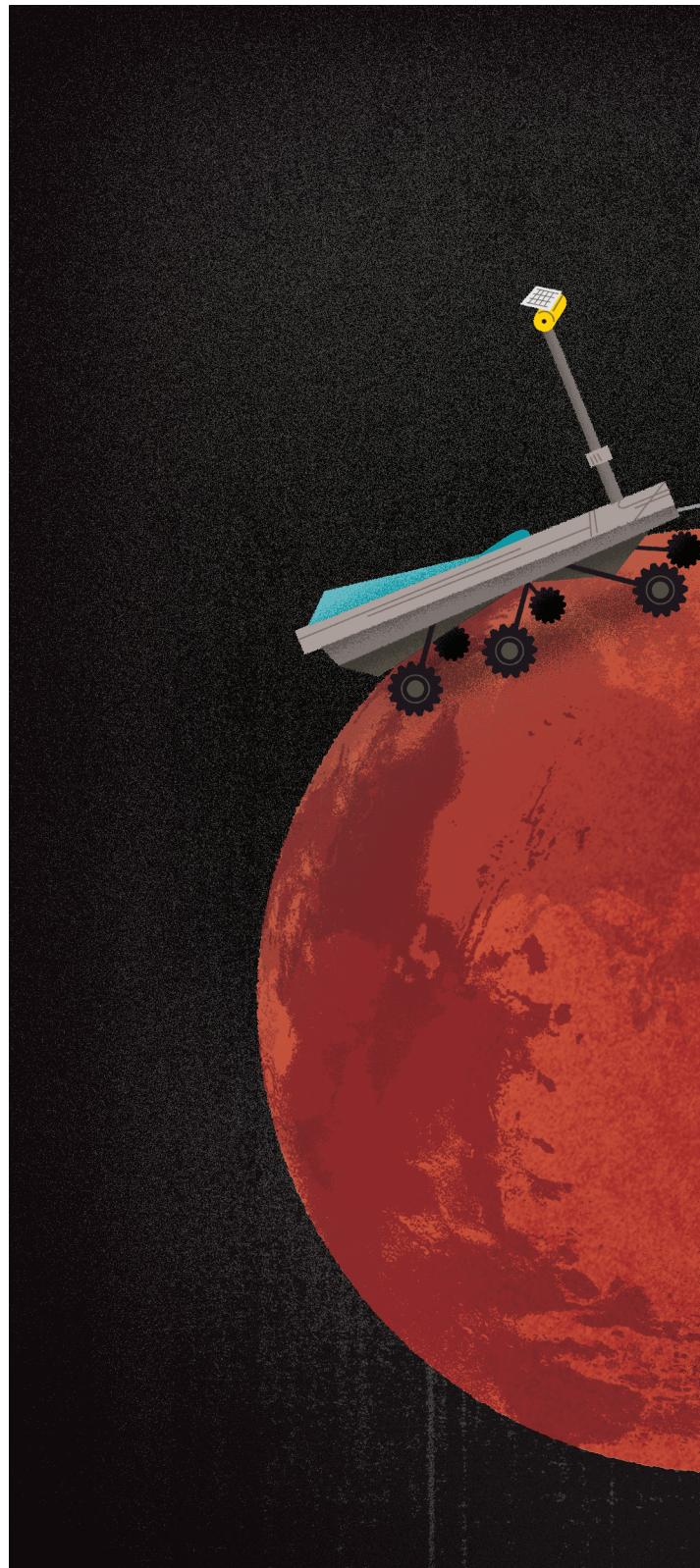
Systems Roadmap for the next quarter century, a document that discusses such advanced possibilities as UAVs delivering cargo to soldiers on the battlefield or flying UAV missions in coordinated swarms.

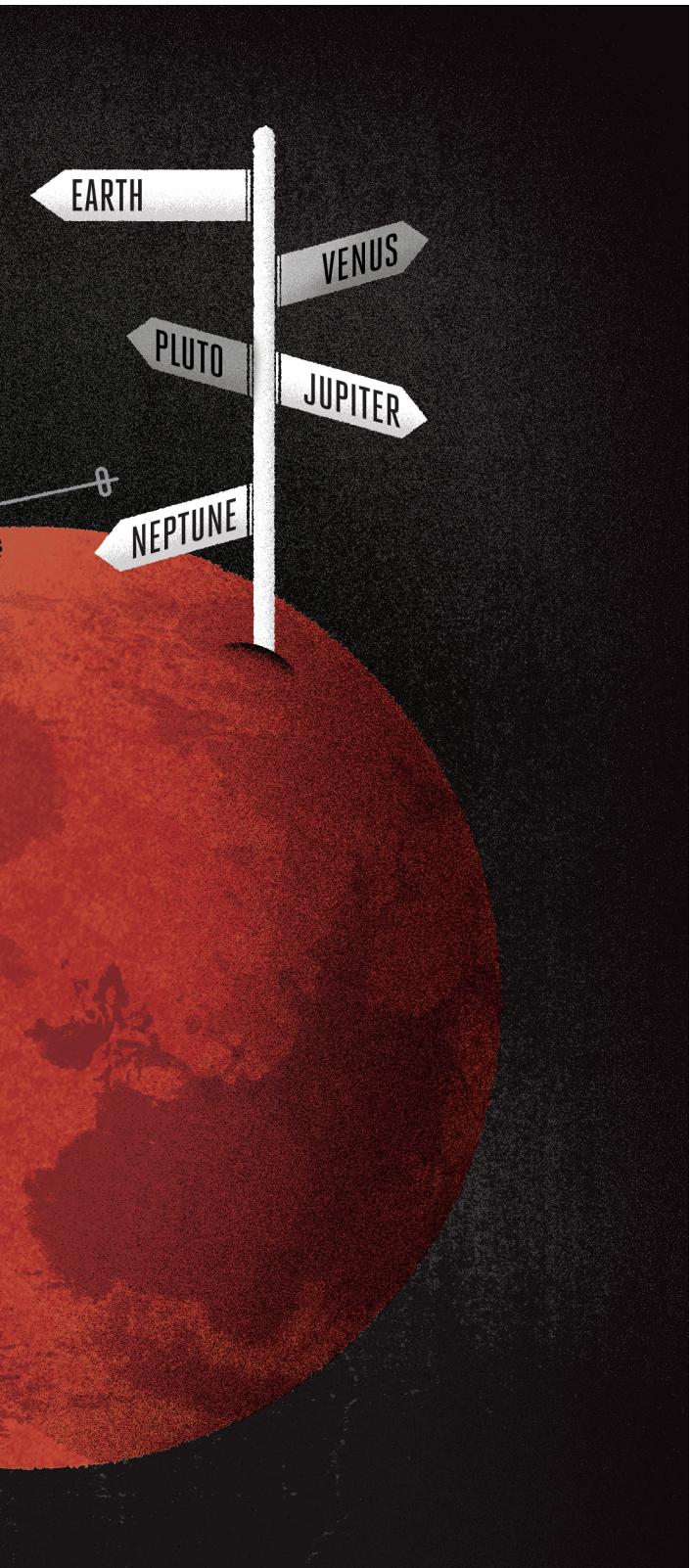
Military UAVs still have a poor safety record compared with piloted aircraft, but as trust in them mounts, there's little doubt that their use will expand and spill over into civilian applications. "There's a hunger out there in the commercial sector for this type of technology—for use in everything from UPS and FedEx flights, pipeline surveys, forestry, logging, law enforcement—just about anything you can think of that uses aircraft today could benefit from a low-cost, reliable, and safe unmanned aircraft technology," says retired Army Lt. Col. Glenn Rizzi, senior advisor to Col. Sova.

It will, of course, be a long while yet before the typical traveler will be comfortable taking an airliner with no pilot on board. But well before that, we're likely to see UAVs of other varieties flying in civilian airspace.

Understandably, aviation authorities need to police developments here cautiously so that the safety of air travel isn't compromised. But the steady advance of communication and automation technology—which is already quite sophisticated in today's airliners—will surely open the skies to pilotless aircraft of many types. As Rizzi contends, "The future [of UAVs] is only up."

—DAVID SCHNEIDER





# Planetary No. 8 Rovers

## ARE WE ALONE?

**Planetary rovers attempt to answer the most profound question in science**

PETE THEISINGER stands at the back of the mission control room, his round, mustachioed face frozen in a nervous grin. Hunkered down at long rows of computer consoles, his engineers sit on the edges of their chairs. NASA's Jet Propulsion Laboratory is hanging on the brink of a jubilant victory—or a devastating failure.

Then the black-and-white images appear on a big projection screen, and the room explodes in cheers. Some 200 million kilometers from Earth, a little robotic rover called Spirit, built here in Pasadena, Calif., has awakened and called home, sending images of what it is seeing. And what it is seeing is the rocky plain of Gusev Crater, in the southern highlands of Mars.

Theisinger, the project manager of the Mars Exploration Rover mission, has only one word: "Wow."

Wow, indeed. Since that night in 2004, Spirit and its twin rover, Opportunity, which landed three weeks later, have embarked on an extraordinary journey

of discovery. Designing, constructing, launching, and landing those rovers on Mars has become NASA's most thrilling and successful planetary mission ever.

Why bother to study rocks and dirt from a cold, desolate, remote world? Because the geology of Mars embodies a history that should help unravel our own, and because those Martian rocks may also hold the answer to a question we've been asking ourselves for a very long time: Are we alone?

"Finding evidence that life arose independently on another planet would be one of the most profound discoveries that humans could ever make," Steve Squyres, astronomy professor at Cornell University and the mission's chief scientist, writes in *Roving Mars* (Hyperion, 2005), his candid account of the project. Mars, he adds, "is a world that can help us learn our place in the cosmos."

In the past decade, planetary rovers have emerged as one of the most amazing exploration tools humanity has ever seen. They have also fostered scientific and technological innovations that should find applications on Earth, in areas such as

FRANK CHIMERO

## BET YOU DIDN'T KNOW

NASA's new rover, Curiosity, has approximately 50 000 parts—from microscrews to heavy actuators—or more than twice as many as an average car.

autonomous robotics, remote sensing, and materials engineering.

Above all, these robotic explorers have demonstrated that unmanned missions offer formidable rewards, with immensely smaller costs and risks than manned ones. Manned missions will surely remain on NASA's agenda; human boot prints on extraterrestrial soil are too powerful a draw to relinquish. But the success of the Mars rovers has proved that before we send humans, we ought to send robots.

NASA is not alone in advancing rover technology. The European Space Agency, in a joint mission with NASA, is building a next-generation Mars rover, called ExoMars, for launch in 2018. And other countries and even private companies have dreamed up rover plans of their own.

Right now, however, JPL is commanding all the attention. A new rover, the Mars Science Laboratory—named Curiosity in a contest—is scheduled to launch later this year. Compared to its golf-cart-size predecessors, it's a monster of a machine, the size of a Mini Cooper, weighing in at 900 kilograms, equipped with a nuclear power supply, and carrying 10 scientific instruments of unprecedented sophistication, including an advanced analytical system for detecting organic molecules. The mission: Determine whether conditions for life existed on Mars and were preserved—and if they were, find a sample.



**MONSTER ROVER:** The size of a small car, Curiosity is equipped with a nuclear power supply and 10 scientific instruments.

NASA IS LIKE a planetary system where personalities, politics, budgets, and schedules revolve around each other in erratic orbits. Every now and then, these celestial bodies align and a promising mission becomes possible. That's how the idea of sending rovers to explore the geology of Mars emerged in the mid-1990s.

Every space mission builds on its predecessors. Before Spirit and Opportunity, a Soviet program called Lunokhod put an eight-wheeled, solar-powered rover on the moon in 1970 and another one in 1973. Controllers on Earth steered the rovers and operated their

cameras and instruments in near real time.

But as interest shifted from the moon to more distant parts of the solar system, flyby probes, orbiters, and landers came to dominate the scene. Rover missions seemed too daunting—or merely unnecessary, in the case of a ball of gas like Jupiter.

In the mid-1970s, NASA's Viking program put sophisticated landers on Mars to search for signs of life. They didn't find any, but then again, they were pretty much looking at their feet. That's the main drawback of landers: They're stuck in one place. You could have the most

intriguing rock sitting in front of you, but if you can't get to it, you'll never know what secrets it might hold.

Rovers made a comeback in 1996, as part of NASA's Pathfinder program. Pathfinder was essentially a lander mission, but it carried a small rover named Sojourner in its belly. The rover successfully roamed around, snapping photos and analyzing the chemical elements of rocks.

The results led NASA to start planning a more ambitious rover mission. In 1999 alone the agency lost two spacecraft, the Mars Climate Orbiter and the Mars Polar Lander, and it desperately needed a successful mission.

It was good timing. JPL had been developing a number of navigation and robotic technologies that it could put to use. After a series of solicitation bids, review panels, and approved, canceled, and newly revived proposals, one idea stood out in particular. Could NASA use Pathfinder's successful landing approach to place not a lander but a rover on Mars? This approach would rely on slowing the spacecraft as it entered the Martian atmosphere, using rockets and a parachute, and then deploying air bags to cushion the touchdown.

JPL engineers believed it could work. They would strip the Pathfinder lander down to its basic structure, cram a bigger and better-equipped rover inside, and keep the rest essentially the same. The mission got the green light in mid-2000, and the clock started ticking.

## COMPANY TO WATCH: MALIN SPACE SCIENCE SYSTEMS, SAN DIEGO

Malin Space Science Systems, a small outfit based in San Diego, builds some of the most sophisticated cameras in the space business. As the eyes of two Mars orbiters, the company's cameras took hundreds of thousands of photos of the planet's surface. Now they will do the same on the ground, mounted on Curiosity, which will carry three science cameras, this time able to capture not only still but also moving images.

The launch window—when the orbits of Earth and Mars would be best aligned—was just three years away. That wasn't a whole lot of time to build a complex planetary rover. Yet NASA told JPL to build two, to double the chances of success.

Cornell's Squyres led the science team building the instruments that Spirit and Opportunity would take, while Theisinger headed the engineering team working on the design of the rovers. It didn't take long for them to come to a terrifying realization.

Though things looked good in preliminary studies, when it came time to refine their designs the teams discovered they had underestimated the size the rovers would eventually become. The rovers were too big for them to reuse the Pathfinder landing system. The EDL team—responsible for entry, descent, and landing—scrambled to redesign the parachute and air bag systems. The first tests failed badly, with prototype chutes and air bags blowing to pieces.

Other problems cropped up. Instruments that had been working misbehaved inside the thermal vacuum chamber that simulated the Martian atmosphere. An error in a telecommunications module deep inside Spirit forced engineers to reopen its electronic guts. In *Roving Mars*, Squyres describes one of the commands the software team sent to the rovers quite often during development: SHUTDOWN\_DAMMIT.

At one point, when Spirit was already inside a Delta II rocket awaiting launch, engineers discovered they had accidentally blown the rover's main fuse during the final assembly. The problem nearly made NASA administrators kill the entire mission.

But in the end, the engineers did what engineers do best: They solved problems, one after another, with solutions that were sometimes ingenious and other times just good enough.

The machines they created—each cost some US \$400 million, including launch and operation—are beautiful pieces of technology. Their solar panels unfold like origami. Their so-called rocker-bogie suspension systems allow each wheel to move

up or down independently so the vehicles won't tilt excessively. And their software lets them receive navigation instructions and then drive autonomously, avoiding big boulders and stopping before cliffs.

With panoramic cameras, a microscopic imager, a rock abrasion tool, and three different spectrometers, the rovers made many discoveries about the geology and mineralogy of Mars. Among the most important was convincing evidence that Mars once had lots of water, an ingredient essential to life as we know it.

Expected to last 90 days, the rovers have worked for seven years. Spirit is stuck in sand and probably hasn't survived the last Martian winter, but Opportunity is still roving around. These robots answered many

questions and also raised fresh ones. And that's why NASA is going back—this time with a bigger rover.

FEW ENGINEERING projects compare to building a spacecraft in terms of cost, complexity, and risk. These are one-of-a-kind machines that will face the harshest conditions—crushing accelerations, extreme temperatures, radiation storms—while stuffed with sensitive instruments and moving parts. And of course, once they leave the launchpad, there's no recalling them. The number of organizations that can build jet fighters and nuclear reactors is small. Fewer still can build spacecraft. JPL is one of these.

Tucked in a small campus in the San Gabriel foothills, JPL is NASA's lead

## HONORABLE MENTION

# Flat-panel TVs

## LCD by TKO

**Underdog LCD went from desktop to wall mount**

Engineers have known for decades that getting the cathode ray tube out of the picture would allow TV sets to have bigger screens while making them as wispy as runway models. But plasma displays were too expensive and power hungry to break out of the high end of the TV market, while LCDs, despite their success in desktop computing, were even further out in the cold.

LCDs suffered from blurred images, ghosting, low contrast ratios, and colors that varied dramatically



at different viewing angles. The game changed with several key innovations, notably NEC Corp.'s Overdrive technique, which doubled the standard voltage supplied to a pixel while using half the pulse width (speeding up response times from around 20 milliseconds to about 2 ms today). Meanwhile, the success of LCDs in the desktop

market created economies of scale, lowering the cost per unit. Together these developments induced electronics manufacturers to invest heavily in large-screen LCD technology for television. Energy efficiency and contrast ratio were dramatically improved when LED backlights began to replace fluorescent tubes. By the 2007 holiday season, cheap, svelte LCD TVs had elbowed aside plasma and CRT.

Now children under 15 will give bulky CRTs the same quizzical look they give manual typewriters and pay phones. —Willie D. Jones

facility for the exploration of the solar system. Hardware built here has flown to the moon, Venus, Mars, Mercury, Jupiter, Saturn, Uranus, and Neptune.

Late last year, when I visited Theisinger, he proudly showed me photos and decals on the walls of his cramped office—trophies of his past victories. The 40-year JPL veteran is again leading an engineering team, the one building the Curiosity rover.

Compared to Spirit and Opportunity, the new rover is “an order of magnitude” harder to design and build, Theisinger says.

With a massive 2.3-meter-long arm, the rover will be able to push a percussion drill against rocks to extract samples. Wheels half a meter in diameter will let it traverse difficult terrain, off-road-style. And thanks to its plutonium-238 thermoelectric generator, it will be able to operate in the winter and at latitudes farther from the equator.

These capabilities are key to the success of Curiosity’s mission. To find out whether environments habitable for microorganisms ever existed, the rover will have to go to places and perform scientific experiments beyond what its predecessors could do. The goal is to better understand how the availability of water, energy, and elements like carbon evolved on the surface of Mars.

“With [Spirit and Opportunity], what we can do is imagine what might have happened,” says Caltech geologist John Grotzinger, the mission’s chief scientist.



**WHAT A SIGHT:** NASA managers at the Jet Propulsion Laboratory celebrate after receiving the first Mars images from the Spirit rover.

“With Curiosity, we’re going to determine what actually happened.”

Curiosity will carry 10 instruments from five countries. The most important is known as SAM, or sample analysis at Mars. This set of instruments takes a rock or soil sample and uses a mass spectrometer, a tunable laser spectrometer, and a gas chromatograph to characterize its molecular structure and isotopic composition, and also to test for the presence of organic carbon.

Getting the 80 kilograms of science hardware—Spirit and Opportunity each carried 5 kg—to fit on the rover was one of the project’s biggest challenges. But perhaps even harder was the design of the landing system. The new rover is so big and heavy that air bags won’t work. Like Spirit and Opportunity, Curiosity will travel aboard a capsule known as an aeroshell, and after it enters the Martian atmosphere a parachute will unfurl. But then, still plunging at supersonic speeds, the

craft will fire retro rockets, decelerating to a gentle descent until it’s just 20 meters from the ground. That’s when the rover will detach from a supporting structure and lower itself on cables—much like a commando rappelling from a helicopter.

When the rover touches the ground, explosive bolt cutters will release the cables, allowing the aeroshell to fly away and crash at a safe distance. Steve Lee, a member of the EDL team, describes all this—the “sky crane,” they call it—with a satisfied look on his face. When I suggest that this would make for a good movie, he smiles even more broadly: A downward camera on the rover would capture not only a top view of the landing site but also the entire touchdown action.

NASA knows the power that images of extraterrestrial worlds have to capture people’s imaginations. So it’s no surprise the rover is also equipped with cameras capable of obtaining high-definition stills and movies, which could be converted into 3-D. (James Cameron is a member of the camera team. Really.)

**KNOWING WHAT THE JPL crew went through with their previous rovers, you might think they’ve grown too bold. Can they pull it off?**

The project has already hit some major snags. A novel lubricant-free motor that NASA wanted to use failed during tests, forcing the engineers to go back to traditional designs.

Another setback involved a turbomolecular vacuum pump in the rover’s SAM instrument. It had to be redesigned and retested, delaying its delivery—and leaving project managers wringing their hands.

But as before, the engineers march forward. At JPL’s vast clean room, construction and testing of the rover’s final components proceed at a frantic pace. Launch is scheduled for late November or early December.

Why go to Mars? There are many reasons, JPL engineers will tell you. But some on the team have personal motivations. Pete Theisinger says he once received a letter from a man in Ohio. The man wrote that one day he was watching TV with his young son, and they saw Spirit and Opportunity and the images their cameras had captured of the Martian landscape. The letter included a photo of the man’s son. He was building a rover out of Legos. —ERICO GUIZZO

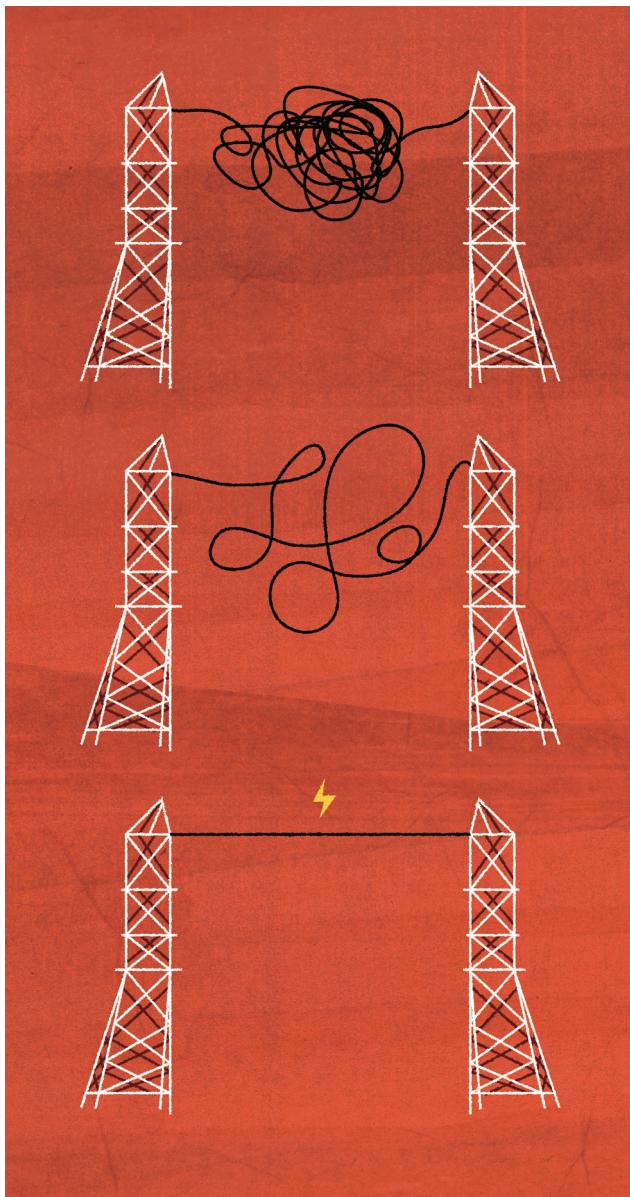
# NO. 9 Flexible AC Transmission

## THE FACTS MACHINE

Flexible power electronics will make the smart grid smart

POWER SYSTEMS MUST juggle supply and demand while guaranteeing glitch-free alternating current 24/7. To deliver it, engineers once had no choice but to design grids that were as passive as the Roman aqueducts, which could carry water anywhere, so long as it went downhill. But over the past decade, a confluence of innovations, regulatory change, and sheer watt-squeezing necessity has hatched a marvelous advance, one that has begun to realize the long-standing dream of pushing current where it wouldn't ordinarily go.

And it's happening not a moment too soon. These flexible AC transmission systems, or FACTS, promise to save energy in a big way by making possible the smart grid, which utilities hope will reconfigure power flows in real time, maximizing throughput and minimizing losses. They should also make it possible to smoothly



incorporate wind, solar, and other intrinsically intermittent sources of energy into the grid.

The key word in the FACTS acronym is the first one: *flexible*. Modern hydraulic engineers use pumps to push water against the force of gravity, so they save immensely on bridges and tunnels in comparison with their Roman predecessors. And think about how aeronautical engineers can manipulate control surfaces from second to second to keep aloft a plane that would otherwise be only slightly more flyable than a brick. Real-time control of power systems promises similar rewards.

FACTS proved its mettle in the 1990s in demonstrations led by the power industry's Electric Power Research Institute (EPRI) and grid equipment manufacturers, such as GE and Zurich-based ABB. Over the past decade, FACTS has gone commercial and is "penetrating the network everywhere," says Claes Rytoft, chief technology officer for power systems with ABB.

Applications vary widely to fit local grid conditions and challenges.

## COMPANY TO WATCH: CREE, DURHAM, N.C.

Efficient, high-temperature silicon carbide switches could slash power losses from silicon-based FACTS controllers by more than 50 percent. Cree leads a US \$3.7 million project with the U.S. government's ARPA-E high-risk energy R&D fund to engineer 15- to 20-kilovolt silicon carbide power modules ready for grid-scale power flows.

"Waking giant" countries such as China and India apply FACTS to maximize the power carried by every single new transmission line they install, thus minimizing the cost of grid expansion. North American and European utilities, meanwhile, rely on FACTS primarily to tame the unruly output from wind turbines that could otherwise destabilize their congested grids. The Virginia-based consultancy NanoMarkets projects a steep growth curve for global FACTS installations, from US \$330 million this year to \$775 million in 2017.

**THE FIRST FACTS** controllers emerged in the 1970s as an improved means of balancing the two types of power that coexist on AC networks: active and reactive power. Active power, the familiar watts consumed by lightbulbs and toasters, is the product of voltage and the component of an alternating current that is in phase with the voltage. The component that is out of phase multiplied by the voltage gives the reactive power, which is measured in volt-amperes reactive or VARs (or more commonly, megavars).

Reactive power is a

necessary evil: It does no work, and yet you have to add it to move active power. Reactive power results when electricity flows through an inductor or a capacitor, which causes the current to lag (the inductor) or lead (the capacitor) the voltage. When the current lags, engineers refer to it as negative reactive power; when it leads, they call it positive. It's the negative sort that tends to occur in lines, transformers, motors, and even some generators. Too much negative reactive power will cause the voltage to "sag," a condition that can damage electrical equipment.

And the damage can spread: Inadequate reactive power support during peak periods is a common contributor to cascading failures—including the 2003 blackout that toppled grids from Ottawa to Baltimore.

Typically, utilities compensate for the negative reactive power caused by inductors by injecting positive reactive power into the system. Traditionally, there are two ways of doing that: by patching banks of capacitors into a circuit to convert some of its megawatts into megavars, or by tuning the generators in conventional power stations to produce current waveforms that lead voltage. FACTS got started as a more dynamic solution, and it has become increasingly relevant as deregulation has progressively turned the electricity business into a kind of promiscuous dating game, whereby supply is married and remarried frequently to match demand, sometimes on an hourly basis, and without much regard for the capabilities of the transmission assets connecting those scattered centers of supply and demand.

By means of such matchups, FACTS allows system managers to send more power over a line than it could otherwise support. The increase can be as high as 50 percent, says Ram Adapa, a technical manager for EPRI. Stability enhancement accounts for part of the boost, allowing grid operators to operate lines closer to their thermal limits.

The heart of a modern

## HONORABLE MENTION

## Digital 3-D

*Better, Bit by Bit*

With digital cinematography, 3-D finally makes sense

Thirty years ago, Buzz Hays started his 3-D career with a lesson from Alfred Hitchcock, by helping to restore the master's 1954 *Dial M for Murder* to its original paper-glasses glory. Now he's the chief instructor at the Sony 3D Technology Center, in Culver City, Calif., where he teaches other filmmakers newly learned subtleties of stereoscopic storytelling.

Stereoscopic systems—which present a different perspective to each eye—failed in the '50s. But to critics who say, "Been there, done that," Hays responds that stereoscopy is in a "constant state of refinement," incorporating new projection technologies, brighter images, and better ways to capture footage.

Digitization was the key, says Bruno Sargeant,



who manages television work at Autodesk, a computer graphics company. He says that a completely digital "pipeline" from camera to presentation has finally made 3-D filmmaking financially viable.

Joshua Greer, president and cofounder of RealD, in Beverly Hills, Calif., agrees. Theaters equipped with his company's digital projection equipment account for about 80 percent of the market share, measured in terms of 3-D films' box office receipts. His company's 3-D cinema system uses a liquid crystal filter to circularly polarize light. When combined with today's polarized shades, that means different images for the left and right eyes. Such high-quality systems,

Greer says, were "just not possible before digital came along." Now business is booming: In June of 2009, RealD's light shows jumped out of 2600 theater screens; this past summer, 7500. There were 6 such films in 2008; this year, the company expects there to be 35.

Although some now point to glasses-free systems and even "holography" (which requires projecting images on mist or smoke), Hays says the next big thing will be when "mere mortals" can record and then watch their own films—including those of baby's first step—in 3-D. —Joseph Calamia

## BET YOU DIDN'T KNOW

The world's most sophisticated FACTS controller keeps New York City lit when lines upstate start to max out. The system, completed by the New York Power Authority and the Electric Power Research Institute in 2003, pulls hundreds of megawatts from NYPA's congested Albany circuit and pushes it onto the Catskills line, a feat that has yet to be rivaled.

FACTS controller is an array of solid-state switches, often coupled with capacitors. Typically, the solid-state switches open to tap power from the line and charge a capacitor; then the switches fire in sequence to create a synthetic AC waveform with precisely the needed phase difference between current and voltage. That waveform is then applied to the grid. By precisely varying the phase difference, the FACTS controller can add or subtract reactive power in fine increments.

Impressive as it is, such dynamic voltage regulation is the simplest of the FACTS grid control modes. FACTS innovators went further in the 1990s by exploiting newly developed high-power semiconductor switches that could switch at frequencies higher than the standard 50- or 60-hertz AC cycles.

With relatively advanced switches, such as insulated-gate bipolar transistors, FACTS controllers could simultaneously regulate voltage and surgically remove a variety of glitches in the AC signal. One such FACTS device, the static synchronous compensator, or statcom, has played a decisive role in the more than tenfold rise in wind power capacity worldwide over the past decade. A Siemens-built statcom, for example, is stabilizing flows from the world's largest offshore wind farm, completed this past September, whose 100 3-megawatt wind turbines should feed enough energy to the United Kingdom's grid during the year to supply more than 200 000 homes.

**MASSIVE WIND FARMS** barely raise an eyebrow today, but Charles Stankiewicz, executive vice president at power equipment manufacturer American Superconductor Corp., says that just a few years ago they still rattled many transmission engineers, who viewed their gusty, noisy power signal as a threat to grid stability. Stankiewicz suggests that many of the more than 70 wind farms stabilized by his firm's FACTS controllers might never have been erected without FACTS technology. "It would have been one more excuse that allowed the electric utilities that maybe weren't inclined to accept wind power to basically say, we're not going to do it," says Stankiewicz.

The most advanced FACTS go beyond stabilizing a line to reducing its apparent impedance, so grid managers can actually push more power down it. This application went commercial in 1998, when Brazil commissioned a pair of 1000-kilometer, 500-kilovolt lines to link its northern grid, replete with Amazonian hydropower, to the southern grid serving its coastal population centers. A FACTS controller near the northern end of the line simultaneously drives power and damps down destabilizing feedback signals.

The Brazilian project marked a breakthrough for AC transmission, where high impedance had previously limited lines to

just a few hundred miles. The payoff was enhanced access to electricity in Brazil's hinterland, according to Stig Nilsson, who launched EPRI's FACTS program in the 1980s and now serves as a principal engineer with Exponent, a Menlo Park, Calif.-based consultancy. Had Brazil relied exclusively on lower-resistance high-voltage direct current (HVDC) technology to deliver power to the coast, it could not have tapped the line along the way to serve interior communities.

HVDC lines passing over as yet unelectrified regions of sub-Saharan Africa have inspired regional discord, and Nilsson says analogous concerns could upend proposals to build HVDC lines in the United States to carry wind power from the Dakotas to the Eastern Seaboard: "People are going to say, 'Why should I allow you to send wind power through my state that I'm not even going to get access to?'"

**INDIA AND CHINA**, meanwhile, have applied FACTS as a cost-cutting tool to ensure that AC lines deliver their full potential and thus reduce the number of lines required. "Instead of building three lines, they may be able to build two and put in a FACTS device," says Nilsson.

EPRI and the New York Power Authority pushed flow control to a technical pinnacle in 2003, showing that coordinated control of two FACTS controllers could pull power off one line and drive it down

another, deftly guiding power around roadblocks in the grid. However, extensive application of such advanced power control to guide flows through meshed grids will require an improvement of FACTS controllers' efficiency and a greater recognition of their value. Grid experts expect both to happen in the years ahead.

Efficiency will rise as FACTS manufacturers integrate energy-efficient silicon carbide semiconductor switches that are being commercialized today for low-power applications and which EPRI's Adapa expects will be available for high-voltage application within five years [see "Company to Watch"].

High-frequency silicon insulated-gate bipolar transistors (IGBTs) used in sophisticated FACTS controllers are just 92 to 94 percent efficient and require active cooling to stay below 100 to 110 °C. The result is that a large controller consumes megawatts of power. By contrast, silicon-carbide IGBTs should be 96 to 97 percent efficient and can operate at 200 °C or higher, slashing the power "tax" for FACTS-based routing of current.

The same ideas will also make HVDC more efficient, because the latest generation of HVDC converters are close technological cousins to advanced FACTS controllers. These newer HVDC systems already make possible underwater connections that are too long for AC cables. They also allow lines to

reach wind farms too far offshore for AC cables and to interconnect AC systems that are adjacent but not synchronized (those of Mexico and Texas and the two main U.S. grid systems, for instance). Silicon carbide switches could make the conversion of AC lines to DC a direct competitor to FACTS as a means of assuring power flows in the heart of meshed grids.

Meanwhile, the leading alternative to both—adding new lines—is not getting any easier. New lines can take a decade to build, if they're not NIMBYed to death by disgruntled property owners or throttled in the womb by environmental advocates, state regulators, and rival power industry players. Each new line also complicates an AC grid, adds Abdel-Aty Edris, until recently a power-electronics expert with Siemens, who helped design EPRI's power-driving FACTS control schemes. "We already have dynamics that we don't control and don't even comprehend," says Edris.

Edris's vision is for a smart grid—both flexible and capable of handling increasing flows—via pervasive application of grid controllers, whether FACTS or HVDC. "My vision is to have a grid which is fully power-electronics integrated—a grid that's as robust as an integrated circuit," says Edris. Rytoft agrees: "Power electronics is the key technology for the grids of the future." —PETER FAIRLEY



# Digital Photography

No. 10

## THE POWER OF PIXELS

**Digital photography changed not only how we take pictures but also how we communicate**

TEN YEARS AGO, photography for the most part meant film. We carried rolls of it on vacation, dropped it off for processing when we got back, picked up our prints, then put them in albums or scrapbooks or, more typically, in cardboard boxes. On occasion, we thought about sending a duplicate to distant relatives, but we'd often forget. Photographs were for documenting our history, for framing, for saving.

What a difference a decade makes! The vast majority of us haven't handled a roll of film in years—it's a retro novelty at best. Digital technology has changed the very nature of photography. Digital images are free and easy and can be instantly distributed. As a result, the vast majority of photos are no longer taken to capture special moments; they're used to communicate the ordinary, with less forethought than a phone call.

Of course, digital cam-

eras didn't simply materialize in our hands a few years ago, although it may seem like it. You could trace their history back to 1969, when the charge-coupled device (CCD) was invented at Bell Telephone Laboratories, or to 1957, when the first digital image scanner was created at the U.S. National Bureau of Standards.

Or you could start in December 1975, when Steven Sasson, an electrical engineer at Eastman Kodak Co., in Rochester, N.Y., became the first person to pick up a digital camera and take a picture.

Sasson, hired by Kodak in 1973, fresh from a master's program at Rensselaer Polytechnic Institute, in Troy, N.Y., was a fish out of water. Kodak was essentially a company staffed by chemical and mechanical engineers, but in the early '70s it started hiring a handful of EEs to develop electronic controls for cameras, like exposure systems and motor drives. One of Sasson's first assignments was to check out the new 100-by 100-pixel CCD chip developed by Fairchild Semiconductor, to see if it would be useful for Kodak.

Sasson decided that the best way to study the chip was to build it into a camera.

Being an electrical engineer, he thought it would be cool to create a new, all-electronic camera, with no moving parts, rather than sticking the CCD into an existing mechanical body. He spent about a year on the effort, working on it in between other assignments, cobbling together the materials he needed from catalogs and used-parts bins. He found a tiny digital-data cassette recorder, adapted an analog-to-digital converter from a Motorola digital voltmeter, and grabbed a lens from an old 8-mm movie camera.

In December 1975 he pointed the completed prototype at a lab technician and took his first picture. He then went to his supervisor and told him that he'd turned that CCD into a working camera.

Sasson recalls his supervisor saying he'd bring some people to the lab for a demo. No, Sasson responded, it's portable. I can bring it to you. His supervisor was amazed.

Sasson started a round of demos, bringing groups of Kodak engineers and executives into a conference room, taking a quick picture of one of them, and then popping the tape out and putting it into a player to show it on a TV screen. "In 1976 we were taking pictures without

FRANK CHIMERO

## COMPANY TO WATCH: TESSERA TECHNOLOGIES, SAN JOSE, CALIF.

In 2008 Tessera bought FotoNation, the company responsible for a vast number of the features that make today's digital cameras so easy to use—like automatic red-eye correction, face recognition, and smile detection. The more that cameras are used for instant communications under suboptimal conditions, the more important such features become. Look to Tessera to continue to make it ever easier to get the perfect shot.

film and viewing them without paper," he says.

Sasson's project never went beyond the prototype stage. At the time, he told Kodak executives that digital cameras wouldn't catch on until they could produce images with 2 million pixels; he thought that day would come in 1990 or 1995. And the executives, he recalls, though recognizing that this would be earth-shattering for the film photography business, believed they didn't need to become too concerned because it wouldn't matter for a long time. Sasson built more cameras at Kodak over the years. Then, in 1990, he moved to the output side of digital imaging, developing color printers. His original digital camera patent, issued in 1978, expired in 1995.

Meanwhile, in 1981, Sony came out with an analog

electronic camera, the Mavica. It recorded images using a television video signal, storing them on a floppy disk.

"I liked it because it woke Kodak up," Sasson recalls. "I also liked it because I knew that it was not going to succeed; it was analog, and to succeed it had to be digital."

About seven years later, Kodak created the first commercial megapixel digital camera, called the Hawkeye II Imaging Accessory. It was sold at a list price of US \$23 000 each to U.S. government organizations; one camera went along on a shuttle mission in 1991.

Then in 1991, the company introduced a commercial black-and-white digital camera, the Kodak Professional Digital Camera System, later referred to

as the DCS 100. In a sense, it was a step back from Sasson's prototype, because it wasn't an all-in-one device; instead, the system tethered a modified Nikon camera to 5 kilograms of electronics in a shoulder bag. It was marketed to news organizations at \$20 000 to \$25 000.

"Journalists just laughed at it," recalls John Henshall, then president of the British Institute of Professional Photography and a consultant with Kodak. But a few did begin using the device, because of two key features—it enabled them to immediately review the captured image on the electronic display, and it was possible to easily transmit these images by dial-up modem.

Kodak's \$9995 DCS 200 in 1992 put all the electronics in the camera. Recalls

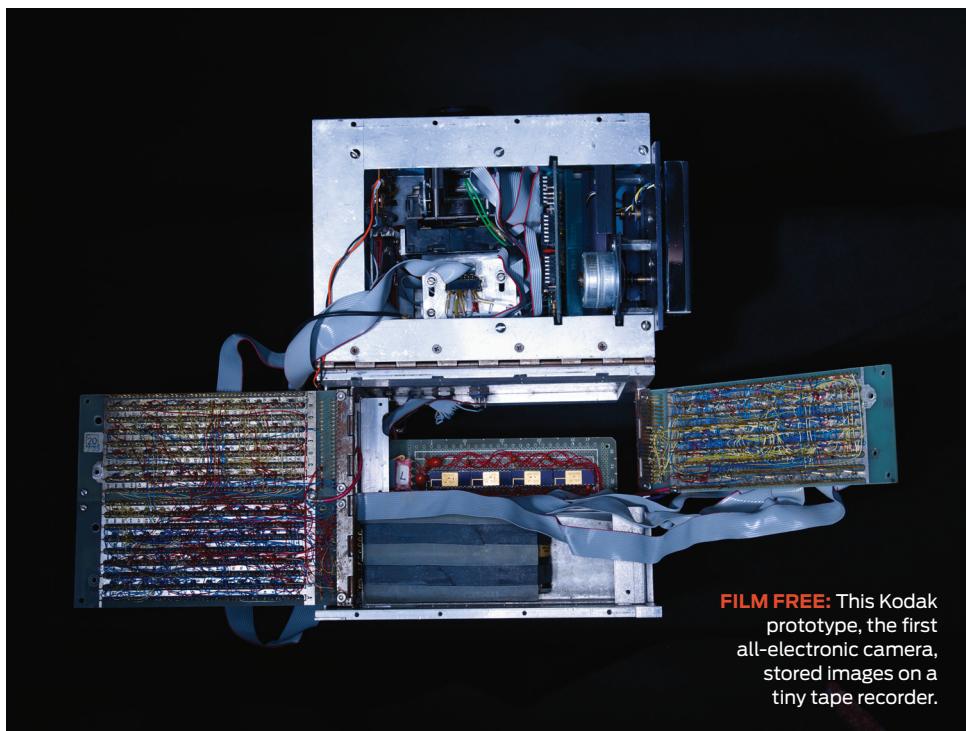
photographer Stephen Johnson, "It was pretty amazing. I took my first images with it walking through the snow in Camden, Maine."

But it took Apple's marketing to finally make Sasson's vision of a handheld all-electronic consumer camera a reality. The under-\$1000 Apple QuickTake 100, designed and manufactured for Apple by Kodak, came out in 1994. At its highest resolution, 640 by 480, it could store up to eight images on its internal memory. It sold only about 50 000 units, but it was a huge landmark.

"Apple legitimized the category," says Alexis Gerard, founder and president of analyst firm Future Image and of the 6Sight Future of Imaging Conference.

It came shortly after the creation of JPEG, the image compression standard that made the most of memory—still very expensive—and of Internet bandwidth. "Having a technology to crunch those huge files down to what the infrastructure could deal with was very important," Gerard says, adding, "Without JPEG, we would have had to wait another five to seven years" for the technology to catch up. And JPEG meant that digital photos taken by different cameras were fully interoperable.

Apple's second digital camera, the QuickTake 150, again from Kodak, offered JPEG compression. After that, things quickly marched forward. The Casio QV10 in 1995 had the



**FILM FREE:** This Kodak prototype, the first all-electronic camera, stored images on a tiny tape recorder.



**SAY CHEESE!** Electrical engineer Steven Sasson took the first-ever digital snapshot in December 1975.



**1991**  
Kodak DCS



**1992**  
Kodak DCS 200



**1994**  
Apple QuickTake 100

first built-in liquid-crystal display. Kodak introduced the first megapixel consumer color camera, the DC210, in 1997. The first camera phones appeared in Japan in 2001; they hit the United States in 2004.

"It was like a snowball rolling down a mountain; it gathered more and more snow until it blew away everything in its track," says Henshall.

The snowball also changed the essential meaning of photography. The principal purpose of photography had been to capture images for posterity. Today that is no longer primary. "Images are being used for more than just memories," Gerard says. "Many are not intended to be stored but purely to communicate information that only has value in

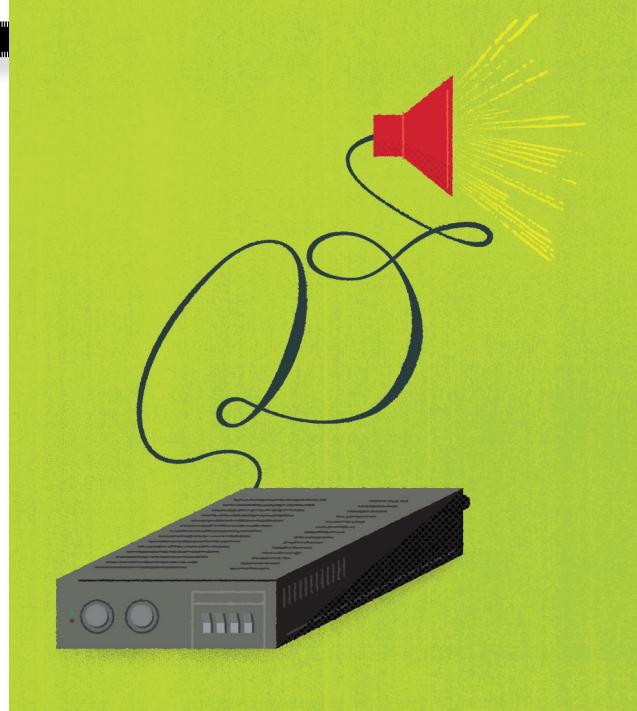
the moment: Where did I park my car? What does this office space we're considering look like?"

Even as an art form, photography is changing, Gerard says. "If you point a camera at a good image in the real world, you will likely get a good image—there is no learning curve. For the first time we have a creative tool that people can jump into right away."

While digital photography has vanquished film, it is far from perfect. Although some people say that the cameras themselves could do a better job at matching what the eyes see—going to three dimensions, in particular—for the most part, it's not the cameras themselves that need improving. "The capability of the cameras being sold today far outstrips the average consumer's ability to use them," Sasson says. The problem is what to do with the images once you've taken them. The scrapbooks and shoeboxes of the film world are being replicated in digital forms, but they're overloaded and becoming impossible to manage.

They're also not necessarily as reliable as a shoebox: Can you trust that your online photo storage company will be around in 50 years or that computers will read old camera formats?

"This is the last frontier," Sasson says. "How do you manage these images? How do you save them for 50 or 60 years, with format obsolescence, changing standards? Images are the only digital files that get more valuable the older they get." —TEKLA S. PERRY



## No. 11 Class-D Audio

### THE POWER AND THE GLORY

A quiet revolution is transforming audio electronics

EVEN IN THE go-go world of high tech, it's pretty rare that a technological leap delivers both markedly superior performance and stunningly greater efficiency. That neat trick happened with class-D audio amplifiers, which now dominate the market for applications in car stereos, home-theater-in-a-box systems, television sets, and personal computers.

Their success has been a long time coming. The first commercially available class-D amps came in the

1960s from the British company Sinclair Radionics (now Thurlby Thandar Instruments), but they didn't work well. Somewhat better ones came along in the 1970s and 1980s: John Ulrick designed a couple of class-D amps for Infinity Systems in the early and mid-1970s, and a decade later Brian Attwood did a series of "digital energy conversion amplifiers" for Peavey Electronics Corp. But in those days class-D theory was ahead of implementation, because the available components simply weren't good enough to produce high-quality sound.

The problem was speed: Class-D amps sample the input audio waveform

## COMPANY TO WATCH: INTERSIL D2AUDIO, MILPITAS, CALIF.

Intersil D2Audio sells products powered by its Digital Audio Engine technology, which combines class-D amplifiers with signal processing to minimize the effects of noisy power supplies or harsh automotive environments.

hundreds of thousands of times a second before amplifying it, and it wasn't until the 1990s that cheap and reliable MOSFETs became available that were fast enough to sample a waveform at such high frequencies, says Bruno Putzeys, the chief engineer at Hypex Electronics. Hypex, in Groningen, Netherlands, is a leading maker of audiophile class-D amplifier modules, which are incorporated into products sold by other firms.

"What it took was for a couple of companies to take the plunge," Putzeys adds. Those pioneers were Tact Audio, ICEpower, and Tripath Technology, all of which released their first class-D offerings in the late 1990s. Tact, now called Lyngdorf, rocked the audio community in 1998 with a US \$9800 class-D amplifier called the TacT Millennium, which was designed by the Danish engineer Lars Risbo. It dazzled as much for its industrial design as for its engineering: The amp had a large volume knob with a digital display in its center.

ICEpower was founded jointly by another Danish engineer, Karsten Nielsen, who designed the company's first amplifiers and amplifier modules, and the Danish audio company Bang & Olufsen. ICEpower is best known for its combined power supply and amplifier modules, although its single biggest source of income is its MobileSound line of amplifier chips for cellphones.

Tripath, in San Jose, Calif., was the first to introduce a class-D amplifier

chip, the TA1101, in 1996. It was used in Apple's celebrated Power Mac G4 Cube. Tripath's first big hit, the TA2020, in 1998, could funnel 20 watts per channel into 4-ohm speakers (see "25 Microchips That Shook the World," <http://spectrum.ieee.org/25microchips0509>). It was used in ministereos and early flat-screen TVs. "We were shipping millions of chips every quarter to companies like Samsung, Panasonic, Toshiba, Sanyo, NEC, Onkyo, and Sony," says Adya Tripathi, who was the company's president and CEO.

Large stocks of Tripath chips are still available. They feed an e-Bay market for tiny, ultracheap (as low as \$15) amps from China and also a thriving business among hobbyists and DIYers.

Today almost all of the audio amplifier market, from cheap cellphone chips to unbelievably expensive home hi-fi, is split between class-D and class-AB amplifiers; the latter are the long-established technology, and they still dominate in home audio and also in mobile music players, including iPods, MP3s, and smartphones. Those pocket players use micropower amps, which put out fewer than 100 milliwatts per channel. Class-D chips are available for these applications, but they can't yet match the price of the class-AB chips that are available for a few cents per chip from such giants as National Semiconductor, Maxim, Texas Instruments, Sanyo, and various Taiwanese companies. Millions of those amps



**FIRST CLASS:** Audio amp designer Bruno Putzeys of Hypex Electronics shows that very good sound can come from small packages.

are sold every year. And class-AB isn't even the only other competitor in this fast-growing field: Class-G amp chips share class-D's high efficiency and are also supposedly easier to integrate into a dense and highly complicated system like a smartphone.

Nevertheless, the micropower category is still a big market possibility for class-D chips, Tripathi insists. It's only a matter of time before the huge efficiency advantage of class-D tips the scales in their favor, just as class-AB amps slowly but surely displaced class-A decades ago. Some day, without a doubt, it will be a class-D world.

In the meantime, class-D amps are making steady inroads in the home market, where they can exploit to full advantage modern components that are cheap but have very high performance: MOSFETs just keep getting better and better and cheaper and cheaper. And for the technically inclined, amplifier modules and kits

allow anyone with modest soldering skills to get class-D sound, highly precise and detailed, for a few hundred dollars. One of our favorite kits is the SDS-224 kit (<http://classdaudio.com/index.php/sds-224-kit.html>) from Class D Audio, with its robust power supply.

Class-D amps are starting to do well even in the rarefied high-end niche, where an amplifier can cost many thousands of dollars. Putzeys just completed and tested an amplifier design with total harmonic distortion of 0.001 percent at full power across the entire audio range, scalable to 2000 W and beyond. It is a specification that would have been dismissed as science fiction before class-D amplifiers. At any price.

—GLENN ZORPETTE

### BET YOU DIDN'T KNOW

The first class-D audio amplifier offered to the public, in 1964, was an £8 kit from the British company Sinclair Radionics. Its power output was so far below the claimed 10 watts that *Wireless World* magazine, deluged with complaints, supposedly declined to take future advertising from Sinclair.