ring. Most Harvard footballers stop playing after graduation; they "de-train," dramatically altering their exercise routines and lifestyles as a whole. Determining whether their hearts show signs of irreversible cardiovascular damage could have important implications for professional players, who have far lengthier careers.

A third pilot study addresses the health issue attracting the most public attention: repeated traumatic brain injuries (TBIs)—a class that includes concussions (head injuries that alter brain function) and contusions (bruising of the brain tissue). TBIs can lead to chronic traumatic encephalopathy (CTE), a degenerative brain disease. Through complementary work on humans and mice, researchers are testing a light therapy that shows potential to improve brain function after head injury. William P. Meehan III, assistant professor of pediatrics and orthopedics, is conducting a clinical trial in which concussion patients receive treatment three days a week, for six weeks, with red and near-infrared light directed at their skulls. He hypothesizes that this red light increases the metabolic activity of the cells, which in turn produce more ATP, a molecule that carries energy within cells, thus helping the brain recover.

His colleague Michael Whalen, a neuroscientist at Mass General, reports that if concussed rodents are treated with laser light immediately after an injury, testing an hour later shows "significantly improved cognitive outcome." But his lab has also found that any therapy that improves cognitive outcome after a concussion might actually worsen it after a contusion. "If you lump all the patients together, you're hurting some and helping others," Whalen cautions. By studying mice, he hopes to gain insight into the molecular mechanism behind cognitive dysfunction, and find out why this occurs.

The next round of funded research projects begins this June. The winning proposals include a soft, "smart" knee brace that protects a player without limiting motion, and a new self-titrating drug-delivery system to relieve arthritis after injury. Other studies aim to prevent brain damage: an antibody therapy that removes the malformed proteins in the central nervous system that destroy brain cells, and a mobile scanning device that monitors the movement of athletes' brains in real time, on the field.

"Let's not kill football yet," urge the study's principal investigators, in a May editorial in the *Pittsburgh Post-Gazette*. But rather than wait for evidence about whether the sport is safe, they argue, "We need results fast to develop new diagnostic methods and treatments" for those already in the game. That way, even as football's toll on its top athletes is being assessed, medical advances may allow players to experience what a Harvard Stadium plaque calls "the joy of manly contest"—with fewer of its dangers. —SOPHIA NGUYEN

HARVARD FOOTBALL PLAYERS HEALTH STUDY WEBSITE:
footballplayershealth.harvard.edu

CONNECTED CORPORATIONS

Why the Internet of Things Is Big Business

For those outside Silicon Valley, the "Internet of Things" is a buzzword often associated with seemingly superfluous toys for early-adopting consumers: the expensive Apple watch, the oft-ridiculed Google Glass, or a "smart" refrigerator that senses when the milk jug is empty. So when Sarnoff professor of business administration Marco Iansiti began looking at how businesses have been transformed by the growing number of everyday objects connected to the Web, the first questioned he asked was: Is the hype real?

For Iansiti and associate professor of business administration Karim R. Lakhani, the answer is an unequivocal yes. We have entered an age of "Digital Ubiquity," they wrote in *Harvard Business Review (HBR)* last fall. Sensors in gadgets, appliances, and machines generate an unprecedented and growing volume of data that is increasingly easy to share wirelessly. The ability to ag-

Illustration by James Yang

gregate and analyze these data at a massive scale, the authors argue, has begun to change the very nature of how businesses create value and make money in nearly every industry.

The researchers point to recent efforts at General Electric that have turned the century-old company into an unexpected digital-transition success story. In the last few years, GE and other electronics companies have seen exponential growth in the volume, velocity, and variety of data that they collect, Lakhani explains, forcing "companies that did not think that they were in the software business to become good at software development."

As a result, GE began to take stock of the software underpinning its widely varied product lines. The company's 12,000 software professionals were working on 136 different products, each with its own underlying technical platform, but only 17 of these were profitable. In an effort to streamline this work, in 2011 the company launched a new business unit, GE Software, a centralized office to develop one underlying program for all its devices.

The "industrial internet" is the term GE executives have coined to refer to these digital integration efforts. The corporation's new approach to selling wind turbines exemplifies the opportunities and challenges that this connected future presents. Before the world went digital, the easiest way for GE to add value to a customer's wind farm was to sell it more turbines. Now sensors wirelessly transmit data on performance and maintenance back to GE, which can replace worn-out parts before they break and adjust controls for torque, pitch, and speed in real time. By keeping the turbines running more efficiently, GE has created worth without selling more products—and a new price model allows the company to capture part of this value. Rather than charging for the turbine alone, the sales force can quantify the wind farm's data-driven savings and charge a fee based on the value of that optimization. These new ways of creating and capturing value have gone hand in hand with fundamental changes in GE's operations. The company has invested billions in GE Software, and retrained its sales force to focus on long-term contracts and pay-for-performance.

GE's example underscores why the Internet of Things—a widespread form of digital disruption—need not be a death

knell for large, legacy companies. New business models can be built on the loyalty that GE has spent decades building among its customers. "These assets are amazingly powerful, and if you can just find a way to unlock them, it becomes a great advantage," Lakhani says. But monetizing such assets "requires new business models."

For the past two years, Lakhani and Iansiti have taught a popular new elective course on digital innovation, and they're writing a book on the subject. The main takeaway, they say, is that these transitions are blurring the boundaries that once cordoned off the tech industry.

Take the highly publicized case of Nest, the connected thermostat company that Google bought for $3.2 billion in 2014. Nest offers customers convenience: smartphone users with remote access need never again wonder whether they turned down the heat before they left for vacation. By giving individuals more dynamic control over energy usage, Nest helps customers save—potentially disrupting the traditional, $3-billion thermostat market. But from Google's perspective, Lakhani and Iansiti wrote in *HBR*, Nest creates value that goes far beyond just the sum of the savings on each person's energy bill. Google has, more significantly, bought access to an unparalleled data set about how energy is generated, consumed, and wasted—an opening into a $6-trillion energy sector (see "The Risk of Inaction," May-June 2015, page 68).

The Internet of Things promises to change the way consumers live. But the industrial shift—forcing companies far beyond Silicon Valley to join the tech world—might be even more significant. ~STEPHANIE GARLOCK

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ECONOMIC INSTRUMENTS

Dealing with Debt

The great recession fades from memory, but its effects linger. Nations around the globe still carry its legacy in the form of substantial public and private debt. How governments have dealt with such "debt overhangs" in the past 200 years is the subject of a paper by Carmen Reinhart, Zombanakis professor of the international financial system at Harvard Kennedy School; Vincent Reinhart of the American Enterprise Institute; and Kenneth S. Rogoff, Cabot professor of public policy. The authors say that many observers have forgotten about some of the tools that even advanced economies have used in the past to lessen their obligations.

The aftermath of the recent recession was unusual, Carmen Reinhart pointed out in an interview, in that the levels of debt incurred were more characteristic of the accrued sums confronted in postwar periods like those following World Wars I and II, but the inherent recovery mechanisms typically seen at war's end—the return of a larger labor force, the deployment of resources to economic goods rather than wartime production—did not apply. The reason that debt levels are now so high has everything to do with context, she explained. In addition to government debt, there was massive private borrowing by individuals and the financial sector in advanced economies around the world before the crisis; they took advantage of low interest rates to finance spending—a process now repeating itself in emerging Asia and elsewhere, she said. When sub-prime borrowers defaulted on their mortgage payments, financial institutions were left with the debt. Pension funds also carry large liabilities on their books, mainly related to demographic pressures associated with an aging workforce.

During the ensuing recovery, much of the private and institutional debt was converted to government debt (both in the United States and abroad, notably in Ireland and Spain), through assistance to distressed financial institutions and through mortgage-relief programs for qualified homeowners, for example. That's a positive development, Reinhart said, because officially held debt (i.e., held by a government, multilateral institution, or central bank) can be restructured more easily than privately held debt.

Today, the debt levels in many advanced economies exceed 100 percent of gross domestic product (GDP). In the United States, for example, government debt is currently 105 percent of GDP, a level from which most governments have historically tried to retreat (as a hedge against the possibility that they might need to borrow during a *future* catastrophe). The ideal exit strategy from large debt overhangs,

Illustration by Adam Niklewicz