The "Internet of Things" is the networked interconnection of objects—from the sophisticated to the mundane—through identifiers such as sensors, RFID (radio-frequency-identification) tags, and IP (Internet Protocol) addresses. Ford's Tool Link system, for example, builds sensors into vehicles, including the Ford Transit Connect, so that when the driver presses a button, the dashboard displays an inventory of all onboard tools. A similar system for homes would show you an inventory of all clothes that are supposedly in your suitcase or objects in your briefcase.

Sensors form the edge of the electronics ecosystem, in which the physical world interacts with computers, providing a richer array of data than is available from keyboards and mouse inputs. Currently, someone at a keyboard has input most of the information on the Internet. We are at an inflection point, however, at which more Internet data originates through sensors than keyboards.

The goals for the Internet of Things are, first, to instrument and interconnect all things and, second, to ensure that all those things are intelligent. Recall that the Bay Bridge linking San Francisco and Oakland, CA, had to close for several days last October after metal pieces fell onto the roadway. This
scenario would likely not have happened in a world shaped by the Internet of Things. Instead, thousands of accelerometers on the bridge would have registered the vibratory signature of impending failure. A bridge the size of the Bay Bridge might have 10,000 sensors; a small overpass, 100.

Combining the number of infrastructure sensors with the number of sensors in personal devices, such as cell phones, yields a round number of 1000 sensors per person that manufacturers will develop and deploy over the next 10 years. With a world population in the billions, this figure would translate to more than 1 trillion sensors. That many sensors collecting data implies a lot of data manipulation, which in turn implies a computing cloud—that is, the use of large numbers of computers, often over distributed data centers, to seamlessly process and store large amounts of data. At a typical data rate, 1 million sensors running 24 hours a day would require 50 hard disks running in parallel to capture the 20 petabytes of data these sensors would create in just six months. Companies that are already deep into cloud computing are jumping into the Internet of Things as a significant new business opportunity for their expertise. Two notable examples are IBM, with its Smarter Planet program, and Hewlett-Packard, with its CENSE (Central Nervous System for the Earth).

HP is using its MEMS (microelectromechanical) expertise, which it developed to provide fluid sensors for printer cartridges, to create accelerometers that are as much as 1000 times more sensitive than today’s commercial products. The tiny MEMS accelerometers are the first CENSE sensors; follow-up sensors will include devices for light, temperature, barometric pressure, airflow, and humidity.

The first units to enter the field can detect a 10-femtometer positional change—less than 1-billionth the width of a human hair—measuring acceleration changes in the micro-g range. These abilities make the units approximately 1000 times more sensitive than the consumer-grade accelerometers that a Wii, an iPhone, or an automobile’s air-bag system currently uses (Figure 1).

Apart from the cost of the overall computing network, the sensors themselves, especially 1 trillion of them, represent a significant investment in infrastructure. Peter Hartwell, senior researcher for information and quantum systems at HP Laboratories, believes that the only way for large-scale sensor networks to become economically viable is to increase productivity and efficiency, thereby offsetting the cost of the network: "Look at the silicon that's embedded in a ski pass, for example. There’s no deposit for that chip; it’s literally free because the value it adds in replacing a lift operator [means that] the resort can afford to give away the [chips in the] passes for free." Networked sensors add value that will more than offset their costs, he says.

Although the cost of large-volume silicon hardware does tend toward zero over time, there's more to a sensor node than the silicon. Wireless-sensor nodes have four general components: the sensor and its signal-conditioning circuit, the microcontroller, a radio transceiver, and a power source. The first three components benefit from Moore's Law and rapidly grow in capability while dropping in price. However, the power source doesn't rely on silicon integration and receives no such benefit. Whereas batteries, supercapacitors, and energy-harvesting devices have seen significant improvement over the past several years, energy storage and harvesting do not in general benefit from economies of scale. The power available is still about the same with a fixed budget on the order of milliwatts. The rest of the sensor nodes can now do more with that fixed power budget, however. Nonetheless, dedicated wireless-sensor nodes—for the near term at least—will have a formidable price hurdle to overcome.

Giant corporations such as HP and IBM are not the only pathway into the Internet of Things. For
example, Pachube, an open-source-based private company, allows creators and users with automatically generated sensor data to upload it to the Pachube site for the Pachube community's use. Pachube's generalized data-brokering platform is a way for small companies and researchers whose expertise lies in developing products, rather than networking, processing, and storing data, to access the Internet of Things (Reference 1).

In addition, the Internet of Things isn't restricted to fixed, formal network architectures. Ad hoc sensor networks can also form around personal mobile-communication devices. If you have a smartphone in your pocket, purse, or backpack, you're carrying a variety of sensors. For example, the iPhone senses location, motion, direction, sound, and images through its GPS (global-positioning system), accelerometer, digital compass, microphone, and camera, making you a walking sensor node (Reference 2).

Smartphones can communicate with other users, sending location and sensor information. The information can be as simple and local as "Where are you?" for parental monitoring of a teen's whereabouts, or it can be more complex. "Real network power may come when fixed formal networks can link up with ad hoc networks," says HP's Hartwell. "For example, speed and location data from mobile phones can mesh with smart highway sensors."

The preponderance of mobile devices grooms humans to better support systems for sensors, training us to make sure our cell phones and mobile devices are well-charged; otherwise, we can't talk or entertain ourselves with music and videos. Wireless headsets introduce another power source. If you want to monitor a person's physical state, there are few better places to put a sensor network than on your head, and Bluetooth headsets introduce another battery, which you must frequently charge, right on your head. We as consumers are enabling the power environment for human-based sensor networks.
Ping, a prototype hoodie with a wireless interface, alerts wearers when their Facebook pages have changed and allows quick gestural Facebook responses (Figure 2 and Reference 3). Keyboard-avoiding Facebook users are probably not such a huge market that they will define input/output design for portable devices, but they do represent a growing need to monitor and react to people who may not be well-behaved I/O devices for computers. An example of this growing market is the elderly. Full-time care for elderly patients who are at risk of falling is expensive, and, from an independent-minded patient's point of view, not necessarily desirable. Wearing an accelerometer-equipped, wireless node that sends an alert when it senses a fall can be a substitute for full-time personal care.

For some patients, adjusting their environment itself may be part of their treatment. Speaking at EDN’s March 2010 Designing with LEDs Workshop, Cary Eskow, director of Lightspeed, explained that light in the blue spectrum affects our alertness and attitude, so there are times during the day in an elderly-patient-care facility when blue light is appropriate for some patients. Rather than periodically wheeling patients to the Blue Room, a sensor-driven lighting network can adjust a room's light color—but only when the appropriate patient is present. For this scenario to happen, the room must sense which patients are present and adjust the light for the time of day.

Electronic health records will play an increasingly important role in future health care and healthcare costs. These records currently rely on manual input, limiting the accuracy and amount of data someone enters. Accessing patient information, including identification and vital signs, directly from sensors will correct both problems. Again, however, the sensors must be networked for real-time feedback. Just as important, sensor-based patient monitors can help in understanding disease. Rather than relying on patients to fill out questionnaires about their health history and habits, sensors will do it more accurately and more often. Networked medical information that combines results from thousands or millions of subjects will point out problems and suggest possible methods of treatment.

The full-blown, networked system of a trillion sensors is probably at least 10 years away, but an
example of a smaller sensor network would be within buildings, ranging from private homes to commercial buildings of millions of square feet. Networked, or "smart," buildings automatically dim or turn off lights when people leave and adjust energy use based on occupation. The focus of smart homes or smart buildings is energy efficiency, but these networks all rely on a network of sensors to determine people's usage in concert with environmental effects, such as temperature, humidity, and time of day.

Redwood Systems uses Ethernet, ubiquitous in most commercial buildings, to both power and control its buildings' lighting, but the network is not limited to lighting management. Brent Boekenstein, director of business development, refers to Redwood's network system as a rich sensor network in ceilings, enabling every light bulb to have both a sensor and an IP address. He uses as an example one company in a humid Asian environment that had a problem with mold in the ceiling. The company added a mold sensor into the building's lighting platform. Redwood's platform can work with both LED and fluorescent lights.

LED lighting is a good example of how sensors and the Internet of Things can increase the value of an environment. LED lights, although efficient, are not significantly more efficient than fluorescent lights in many applications, and they are significantly more expensive. However, LEDs have additional functions, such as dimmable light intensity and color control. Disney Cruise Lines has fitted its less-desirable interior, windowless staterooms with round flat-panel screens, or "virtual portholes," which display a live video of the outside environment (Figure 3). The porthole can sense when people are present and superimpose interactive Disney characters; as a result, the rooms command a premium price. Add LED lighting to the light network, and a room with virtual windows can mimic outdoor lighting, complete with dimming on overcast days and day-to-night light cycling.

In a world in which common objects have their own IP address and your cell phone might be talking to them, privacy is a significant concern. "Congratulations! You made my list of supervillains," commented an online news article after HP announced CENSE. HP's Hartwell argues, however, that the Internet of Things could develop a sensor network that ensures that the data is valid and still maintain anonymity.

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**For More Information**

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