MIT Technology Review
BUSINESS REPORT

The Internet of Things

Billions of computers that can sense and communicate from anywhere are coming online. What will it mean for business?

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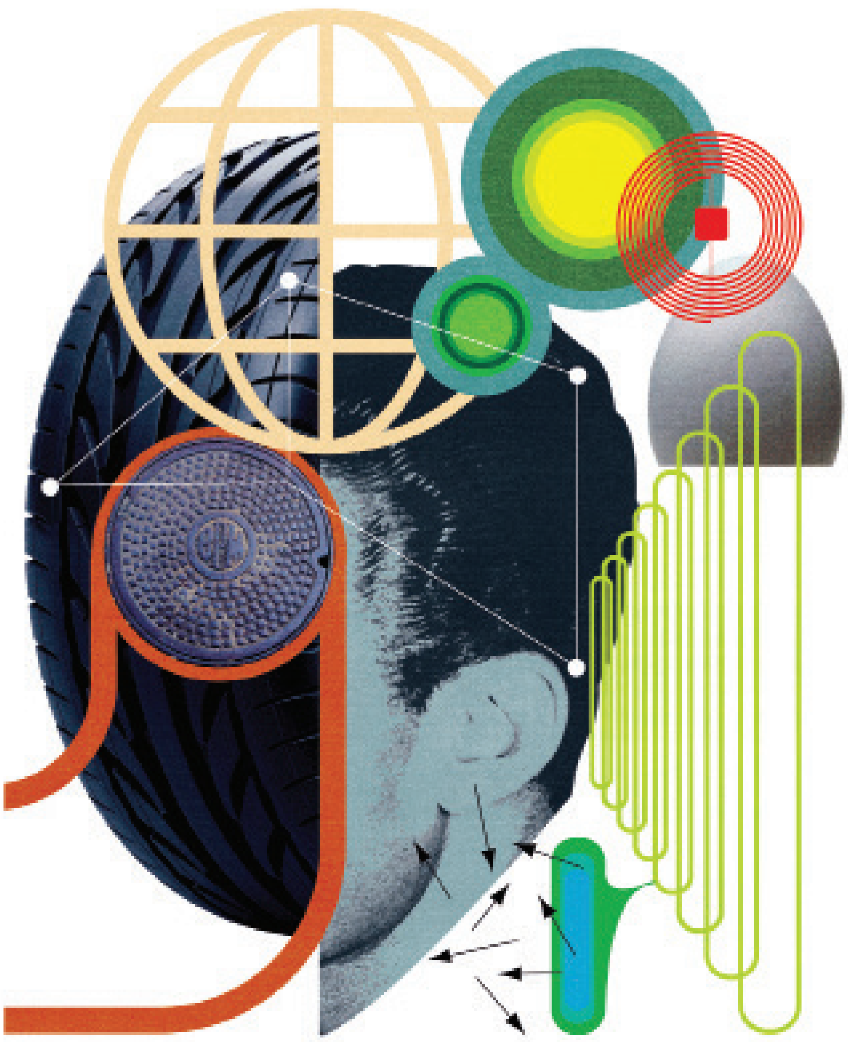
The Internet of Things



STUART BRADFORD

The Big Question

Business Adapts to a New Style of Computer

Are companies ready for billions of everyday objects to join the Internet?

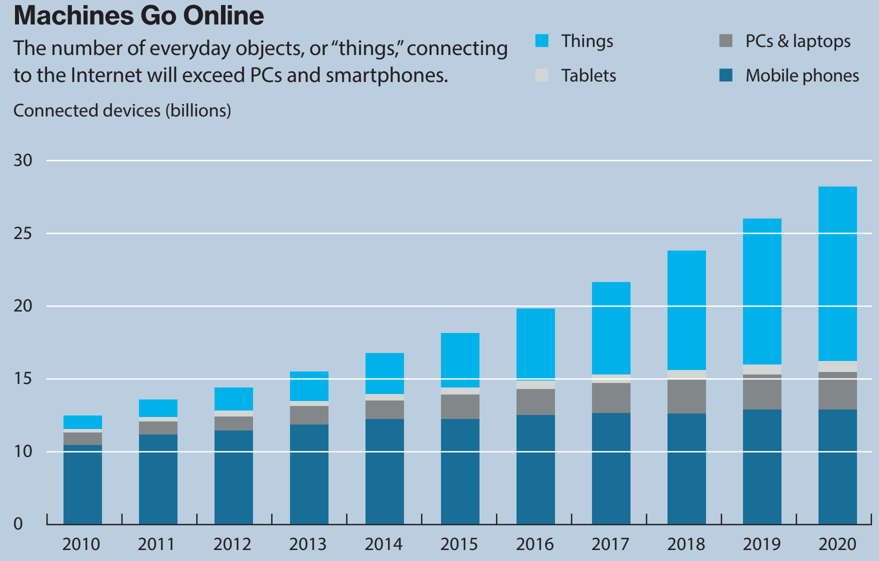
● The technology industry is preparing for the Internet of things, a type of computing characterized by small, often dumb, usually unseen computers attached to objects. These devices sense and transmit data about the environment or offer new means of controlling it.

For more than a decade technologists have predicted and argued about the onslaught of these ubiquitous devices. "There is lot of quibbling about what to call it, but there's little doubt that we're seeing the inklings of a new class of computer," says David Blaauw, who leads a lab at the University of Michigan that makes functioning computers no bigger than a typed letter o.

A key feature is very cheap radios, etched right into silicon. There's one in your smartphone. But now prices are falling to around $5. As they get →

Machines Go Online

The number of everyday objects, or "things," connecting to the Internet will exceed PCs and smartphones.



SOURCE: GSMA

As computers with wireless capability become cheap, it's becoming affordable to connect more things to the Internet, like sensors in sewer pipes, factory machinery, lights, and home appliances.

cheaper, it's becoming affordable to connect more things, like sewer pipes or trash cans. At the University of California, Berkeley, researchers are even designing computers the size of a pinhead to collect data inside the brain and transmit it through the skull. The idea is that human bodies will join the network, too.

It can all sound far-fetched and overhyped. Does anyone really need a smart coffee pot or a refrigerator with a Web browser? Plenty of the inventions do seem silly. On Amazon, product reviewers have had a field day with a $78 digital "egg minder" that reports to a smartphone which egg in a refrigerator is oldest. "Wonderful product!" sneered one. "So many gray hairs avoided by never having to worry about my eggs again."

Yet for every killer app that wasn't, there's another computer-sensor combination that has quietly added to the capabilities of some machine. Since 2007, for instance, every new car in the United States has had a chip in each tire that measures pressure and sends data by radio to the car's central computer. It's starting to add up. The average new car has 60 microprocessors in it, according to the Center for Automotive Research. Electronics account for 40 percent of the cost of making a car.

The Internet of things is especially important for companies that sell network equipment, like Cisco Systems. Cisco has been enthusiastically predicting that 50 billion "things" could be connected to communications networks within six years, up from around 10 billion mobile phones and PCs today. Another beneficiary is the $300 billion semiconductor industry. As Blaauw notes, "Every time there has been a new class of computing, the total revenue for that class was larger than the previous ones. If that trend holds, it means the Internet of things will be bigger yet again."

60
Number of microprocessors in the average new car

But every shift promises pain, too. Large companies like Intel are already reeling from the rapid emergence of smartphones. Intel, with its powerful, power-hungry chips, was shut out of phones. So was Microsoft. Now both these companies, and many others, are groping to find the winning combination of software, interfaces, and processors for whatever comes next.

And it's not just technology companies that must stay alert this time around. The reason, explains Marshall Van Alstyne, a professor at Boston University, is that as ordinary products become connected, their manufacturers may enter information businesses whose economics are alien to them. It's one thing to manufacture shoes, but what about a shoe that communicates? Products could turn out to be valuable mainly as the basis for new services. "You might find the data is more valuable than the shoe," says Van Alstyne.

In this *MIT Technology Review* business report we decided to explore the big question of what new businesses will arise as things get connected. One company making the point is Nest Labs, maker of a slick-looking smart thermostat that's coupled to the Internet. Nest, which was acquired by Google this year, has been clobbering rival thermostat makers. But now that it has a network of thermostats and can control them from afar, it's starting to offer services to electric utilities. On hot days it can selectively turn down air conditioners, controlling demand.

Nest's tests with utilities are still small. But one day, with a few bits sent across a network, the company might put a power plant or two out of business. No wonder this year, in his annual letter to shareholders, Jeff Immelt, CEO of General Electric, the world's largest manufacturer, told his investors that "every industrial company will be a software company."

Gordon Bell, a Microsoft researcher and a pioneer of the original computer revolution, believes no one knows exactly what form computing will take on the Internet of things. But he says that's unsurprising. The importance of the PC and the smartphone became clear only after their development. "The 'Internet of things' is a way of saying that more of the world will become part of the network," he says. "That is what is going on. We are assimilating the world into the computer. It's just more and more computers." —*Antonio Regalado*

Leaders

The Economics of the Internet of Things

As everyday objects get connected, brace yourself for network effects, says one economist.

● Product companies compete by building ever bigger factories to turn out ever cheaper widgets. But a very different sort of economics comes into play when those widgets start to communicate. It's called the network effect—when each new user of a product makes its value higher. Think of the telephone a century ago. The greater the number of people who used Bell's invention, the more valuable it became to all of them. The telephone became a platform for countless new businesses its inventor never imagined.

Now that more objects are getting wired up into networks—street lights, wind turbines, automobiles—there are opportunities for new platforms to emerge. That's why some companies are seeking the advice of Marshall Van Alstyne, a business professor at Boston University who has studied the economics of e-mail spam and social networks.

These days, Van Alstyne studies "platform economics," or why companies such as Uber, Apple, and Amazon are so successful—and what traditional product makers can do to emulate them. *MIT Technology Review*'s senior editor for business, Antonio Regalado, visited Van Alstyne at his office in Boston.

How can I tell if a business is a platform?
If you produce the value, then you are a classic product company. But there are new systems where value is being created outside the firm, and that's a platform business. Apple gets 30 percent of the cut from other people's innovations in its app store. I define a platform as a published standard that lets others connect to it, together with a governance model, which is the rules of who gets what. Business platforms are often engaged in consummating a match. It's a match between riders and drivers with Uber. It's between travelers and spare capacity of guest rooms in Airbnb.

Is connecting ordinary objects, like toasters, to the Internet going to trigger new platforms?
Absolutely, yes. But you can't stop at the connectivity. The technologist's mistake is often to stop simply at the standards, the connections. You also have to add the reasons for other people to add value. That often means allowing recombination of features in ways that you, the original designer, just cannot anticipate. People have combined the functions of the iPhone into hundreds of thousands of apps that Apple never even conceived of. That is also what the Internet of things enables if you design it in the right way.

What are the biggest challenges?

COURTESY OF REDACTIE EMERCE

"Most companies compete by adding new features to products. They haven't been in the business of thinking of how to add new communities or network effects."
—Marshall Van Alstyne

What's an example of this happening?
Philips Lighting just called me. They are adding a series of APIs to their LED lights so anyone can create millions of colors, create romantic mood apps or the colors of a sunset from one of your favorite trips. You can change the lights in your study in conjunction with the stock market conditions. That is the Internet of things, and they're opening it to anyone.

Do product companies have a difficult time making this kind of transition?
They have a really difficult time with the mental models. It's fascinating. Most companies compete by adding new features to products. They haven't been in the business of thinking of how to add new communities or network effects. One of the points I make is that platform business models are like playing 3-D chess.

You estimate that half the top 20 companies in the world, like Google, own platforms. Why are they winning?
There is a strong argument that platforms beat products every time. Think of how the iPhone is absorbing the features of the voice recorder, the calculator, and game consoles. The reason for this is that as a stand-alone product, you're going to have a certain pace of innovation. But if you have opened your product so that third parties can add value, and you have designed the rules of the ecosystem such that they want to, your innovation curve is going to be faster.

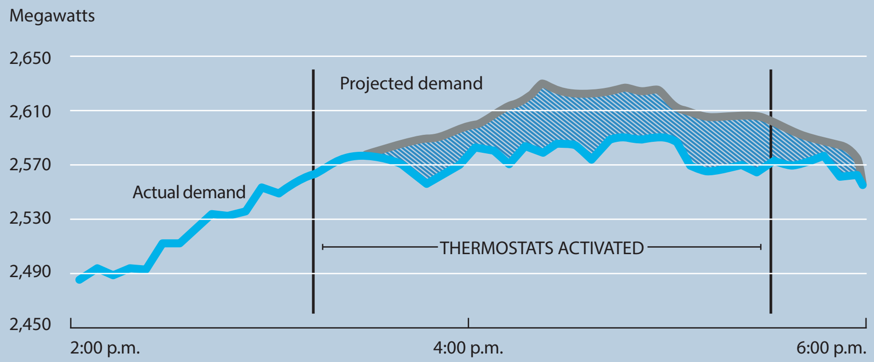
To me this means there are huge opportunities to take away business from existing players in all different kinds of goods. Or for existing players to expand their markets if they are paying attention.

What are some of the next areas for platforms?
It's where you see connectivity is coming in. Cities, health care, education, electricity grids.

What are the biggest challenges?
In many cases, the governance models have not been established. For instance, population density can be determined by mobile-phone distribution. A telecom company owns that data. How do you motivate them to share it? All these sensors are capturing data, but how do you divide the value? Those are the rules that need to be worked out, and that's the missing piece of most of these discussions about the Internet of things. You have to build economic incentives around it, not simply connectivity.

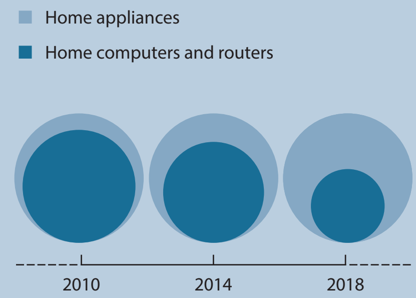
Peak Power

On a 104° day in Austin, remote control of home thermostats helped cut power demand.



Wired Home

TVs, heaters, and other appliances will account for more of the Internet-connected devices in the average U.S. home.



Case Studies

The Lowly Thermostat, Now Minter of Megawatts

How Nest is turning its consumer hit into a service for utilities.

● Google's $3.2 billion acquisition of Nest Labs in January put the Internet of things on the map. Everyone had vaguely understood that connecting everyday objects to the Internet could be a big deal. Here was an eye-popping price tag to prove it.

Nest, founded by former Apple engineers in 2010, had managed to turn the humble thermostat into a slick, Internet-connected gadget. By this year, Nest was selling 100,000 of them a month, according to an estimate by Morgan Stanley.

At $249 a pop, that's a nice business. But more interesting is what Nest has been up to since last May in Texas, where an Austin utility is paying Nest to remotely turn down people's air conditioners in order to conserve power on hot summer days—just when electricity is most expensive.

For utilities, this kind of "demand response" has long been seen as a killer app for a smart electrical grid, because if electricity use can be lowered just enough at peak times, utilities can avoid firing up costly (and dirty) backup plants.

Demand response is a neat trick. The Nest thermostat manages it by combining two things that are typically separate—price information and control over demand. It's consumers who control the air conditioners, electric heaters, and furnaces that dominate a home's energy diet. But the actual cost of energy can vary widely, in ways that consumers only dimly appreciate and can't influence.

While utilities frequently carry out demand response with commercial customers, consumers until now have shown little interest. Nest Labs' breakthrough was to make a device that has popular appeal. "There's a lot of digital Internet thermostats out there, but Nest was able to create a concept around it. They've created something that people are relating to," says Mary Ann Piette, a demand response expert and head of the Building Technology and Urban Systems Department at Lawrence Berkeley National Laboratory.

Once inside a home, Nest starts its real work: gathering data. It has a motion detector; sensors for temperature, humidity, and light; and algorithms that learn residents' habits and preferences.

Once inside a home, Nest starts its real work: gathering data. It has motion detectors; sensors for temperature, humidity, and light; and algorithms that learn residents' habits and preferences and can program heating and AC settings. A Wi-Fi connection brings in weather data and allows consumers to control the system with a phone or Web browser.

Data is just the start. Just as Google parlays what it knows about you into tools for advertisers on the Web, Nest is using its capabilities to create new types of services for utilities to buy. "We can go to utilities and say, 'We've actually got a lot of customers in your service territory who already have a Nest,'" says Scott McGaraghan, Nest Labs' head of energy products. "And [then we] can flip it on."

Austin's municipal utility, Austin Energy, is one of five utilities that have signed up for Nest Labs' Rush Hour Rewards, as the service is called. Air conditioners account for half of Texas's electricity demand on hot days, and that demand for cooling drives the wholesale cost of electricity from less than $40 per megawatt-hour to well over $1,000.

Twelve months ago Austin Energy started offering a one-time $85 rebate to customers who agreed to let it automatically trim their air-conditioning using smart thermostats sold by Nest and other companies. Each company earns $25 for

SOURCE: ANALYSIS MASON; SOURCE: AUSTIN ENERGY; COURTESY OF NEST every thermostat it enrolls, and another $15 per thermostat each year after that.

The "vast majority" of the 5,500 thermostats registered so far are Nests, according to Sarah Talkington, the Austin Energy engineer leading the program. Nest says it finds that roughly half its customers will sign up for demand response when the opportunity is offered.

By the end of last summer, Talkington says, she could log on to a Nest portal and, with a few keystrokes, dial down the next day's demand by nearly 5.7 megawatts. That may seem small compared with the 2,800 megawatts that often sizzle across the Austin grid, but every watt counts. On hot days like September 3, 2013, as temperatures rose to 104 °F, the cost of power spiked to a record $4,900 per megawatt-hour.

Austin had tried residential demand response before, using one-way pagers to turn air conditioners on and off. But the utility couldn't know if customers were home, so it wasn't able to shut off any one air conditioner for long. Nest, in contrast, builds a thermal model of each house and predicts how quickly it will warm up. It can also guess whether people will be home. The result, says McGaraghan, is that Nest can maximize energy savings and minimize annoyance to residents.

Talkington predicts the residential program will enroll enough homes to save more than 13 megawatts through demand response this summer. Even if Austin gives out $2 million in rebates, that is cheaper than increasing power supply by building a natural-gas-fired generator. According to Michael Webber, co-director of the clean-energy incubator at the University of Texas in Austin, new power supply costs $500,000 to $4,000,000 per megawatt of capacity, depending on the type of plant.

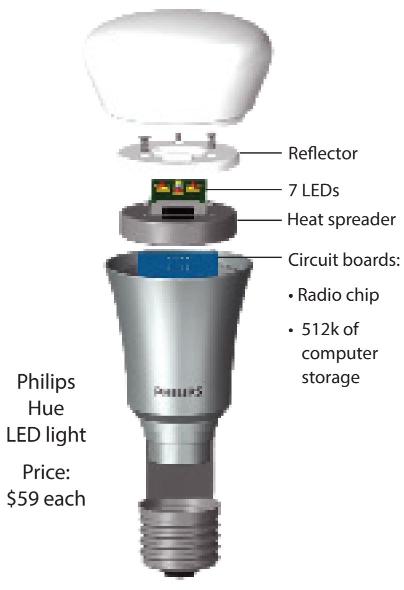
Webber believes that within five years the "vast preponderance" of Texans will have smart thermostats. And Nest knows that whoever builds this network first could win big, especially as other energy-consuming devices, like electric cars and hot-water heaters, also get wired up.

Eventually, the effects of demand response could be profound. Austin's program is designed to manage demand only during the 50 hours each year when electricity consumption tests the grid's limits most. But if demand response can expand to cover the 300 or 400 hours of peak usage, it could entirely shut down the market for "peakers," or gas-fired plants that come online only to sell expensive electricity. "That's a big chunk of money that's at stake," says Tom Osterhus, CEO of Integral Analytics, a Cincinnati-based maker of smart-grid analytics software. "It's in the billions." *—Peter Fairley*

Case Studies

The Light Bulb Gets a Digital Makeover

Electric lights are 135 years old. The Internet is 45. They're finally getting connected.



COURTESY OF PHILIPS

● To demonstrate how the Internet is changing one of the oldest and least exciting technology businesses around, Shane De Lima, an engineer at Philips Lighting, took out his smartphone. A flick across the screen sent a message to a nearby Wi-Fi router and then to wireless hub, which shot a radio command to a chip in the base of an LED lamp in front of us.

A moment later, the conference room where we were sitting darkened.

It may seem like Rube Goldberg's idea of how to turn off a light. Or it could be the beginning of how lighting companies such as Philips find their way from selling lighting hardware into networks, software, apps, and new kinds of services.

The introduction of networked lights is happening because of another trend. Manufacturers have been replacing incandescent and fluorescent lights with ultra-efficient LEDs, or light-emitting diodes. The U.S. Department of Energy says that LEDs had 4 percent of the U.S. lighting market in 2013, but it predicts this figure will rise to 74 percent of all lights by 2030.

Because LEDs are solid-state devices that emit light from a semiconductor chip, they already sit on a circuit board. That means they can readily share space with sensors, wireless chips, and a small computer, allowing light fixtures to become networked sensor hubs.

For example, last year Philips gave outside developers access to the software that runs its Hue line of residential LED lights. Now it's possible to download Goldee, a smartphone app that turns your house the color of a Paris sunset, or Ambify, a $2.99 app created by a German programmer that makes the lights flash to music as in a jukebox.

That's a very different kind of business from selling light bulbs, as Philips has done since 1891. "With the new digitization of light, we have only begun to scratch the surface on how we can control it, integrate it with other systems, and collect rich data," says Brian Bernstein, Philips's global head of indoor lighting systems.

Another look at how lighting systems are changing will emerge this November, when a 14-story regional headquarters for Deloitte, nearing completion in Amsterdam, will be festooned with networked LEDs in each fixture—the first such installation for Philips.

Each of 6,500 light fixtures will have an IP address and five sensors—all of them wired only to Ethernet cables. (They'll use "power over Ethernet" technology to deliver the juice to each fixture as well as data.) The fixtures include a light →

sensor to dim the LEDs during the day, and a motion detector that covers the area directly beneath each light and turns the light off when no one is there. "We expect to spend 70 percent less on light, because systems [give] us much more control," says Erik Ubels, chief information officer at Deloitte in the Netherlands. Additional sensors in the LED fixtures can monitor temperature, humidity, carbon dioxide, and heat, turning the lights into a kind of building-management system.

Prices for LEDs are high but falling quickly. A "dumb" LED that puts out as much light as a $1.25 incandescent bulb now sells for $9 (but uses one-sixth the energy and lasts much longer). That's down from $40 each a couple of years ago. A connected LED bulb from Philips's Hue line retails in the U.S. for $59. But these will get cheaper, too. Philips says a third of its lighting revenue now comes from LEDs, and about 1.7 percent from the newer LEDs that can connect to the Internet.

Many other uses are being explored. A department store in Dusseldorf, Germany, is using LEDs to send out light frequencies that communicate with shoppers' smartphones. Philips has placed street lights in Barcelona that react to how many people are strolling by. —*David Talbot*

Leaders

GE's $1 Billion Software Bet

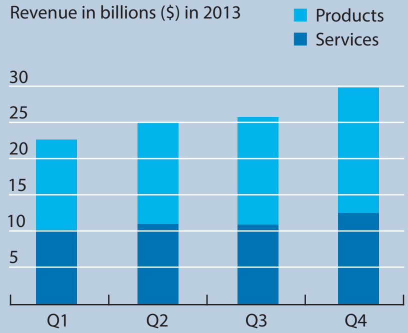
To protect lucrative business servicing machines, GE turns to industrial Internet.

● To understand why General Electric is plowing $1 billion into the idea of using software to transform industry, put yourself in the shoes of Jeff Immelt, its CEO.

As recently as 2004, GE had reigned as the most valuable company on the planet. But these days, it's not even the largest in America. Apple, Microsoft, and Google are all bigger. Software is king of the hill. And, as Immelt came to realize, GE is not that great at software.

Service Play

GE's industrial revenues are split between selling products and servicing them.



"This is a to-the-death fight to remain relevant to our customers."
—General Electric CEO Jeffrey Immelt

Internal surveys had discovered that GE sold $4 billion worth of industrial software a year—the kind used to run pumps or monitor wind turbines. That's as much as the total revenue of Salesforce.com. But these efforts were scattered and not always state-of-the-art. And that gap was turning dangerous. GE had always believed that since it knew the materials and the physics of its jet engines and medical scanners, no one could best it in understanding those machines. But companies that specialize in analytics, like IBM, were increasingly spooking GE by figuring out when big-ticket machines like a gas turbine might fail—just by studying raw feeds from gauges or vibration monitors.

This was no small thing. GE sells $60 billion a year in industrial equipment. But its most lucrative business is servicing the machines. Now software companies were looking to take a part of that pie, to get between GE and its largest source of profits. As Immelt would later say, "We cannot afford to concede how the data gathered in our industry is used by other companies."

In 2012, GE unveiled its answer to these threats, a campaign it calls the "industrial Internet." It included a new research lab across the bay from Silicon Valley, where it has hired 800 people, many of them programmers and data scientists.

"People have told companies like GE for years that they can't be in the software business," Immelt said last year. "We're too slow. We're big and dopey. But you know what? We are extremely dedicated to winning in the markets we're in. And this is a to-the-death fight to remain relevant to our customers."

Peter Evans, then a GE executive, was given the job of shaping what he calls the "meta-narrative" around GE's big launch. Industrial companies, which prize reliability, aren't nearly as quick to jump for new technology as consumers. So GE's industrial-Internet pitch was structured around the huge economic gains even a 1 percent improvement in efficiency might bring to a number of industries if they used more analytics software. That number was fairly arbitrary—something safe, "just 1 percent," recalls Evans. But here Immelt's marketing skills came into play. "Not 'just 1 percent,'" he said, flipping it around. GE's slogan would be "The Power of 1 Percent."

In a stroke, GE had shifted the discussion about where the Internet was going next. Other companies had been talking about connecting cars and people and toasters. But manufacturing and industry account for a giant slice of global GDP. "All the appliances in your home could be wired up and monitored, but the kind of money you make in airlines or health care dwarfs that," Immelt remarked.

There is another constituency for the campaign: engineers inside GE. To them, operational software isn't anything new. Nor are control systems—even a steam locomotive has one. But here Immelt was betting they could reinvent these systems. "You do embedded systems? My God, how boring is that? It's like, put a bullet in your head," says Brian Courtney, a GE manager based in Lisle, Illinois. "Now it's the

SOURCE: GE; COURTESY OF GE

hottest job around." At the Lisle center, part of GE's Intelligent Platforms division, former field engineers sit in cubicles monitoring squiggles of data coming off turbines in Pakistan and oil rigs in onetime Soviet republics. Call this version 1.0 of the industrial Internet. On the walls, staff hang pictures of fish; each represents a problem, like a cracked turbine blade, that was caught early. More and more, GE will be using data to anticipate maintenance needs, says Courtney.

A challenge for GE is that it doesn't yet have access to most of the data its machines produce. Courtney says about five terabytes of data a day comes into GE. Facebook collects 100 times as much. According to Richard Soley, head of the Industrial Internet Consortium, a trade group GE created this year, industry has been hobbled by a "lack of Internet thinking." A jet engine has hundreds of sensors. But measurements have been collected only at takeoff, at landing, and once midflight. GE's aviation division only recently found ways to get all the flight data. "It sounds crazy, but people just didn't think about it," says Soley. "It's like the Internet revolution has just not touched the industrial revolution."

GE is trying to close that gap. Its software center in San Ramon created an adaptation of Hadoop, big-data software used by the likes of Facebook. GE also invested $100 million in Pivotal, a cloud computing company. On the crowdsourcing site Kaggle, it launched public competitions to optimize algorithms for routing airline flights, which can save fuel.

All this could sound familiar to anyone who works with consumer Internet technology, acknowledges Bernie Anger, general manager of GE's Intelligent Platforms division. But he says GE is thinking about what to do next to use connectivity, and more computers, to inject "new behavior" into machines. He gives the example of a field of wind turbines that communicate and move together in response to changes in wind. "We are moving into big data, but it's not because we want to become Google," he says. "It's because we are dramatically evolving manufacturing."

—Antonio Regalado

Emerged Technologies

The Internet of You

As wearable devices get better-looking and more powerful, we'll trust them to monitor and control more of our lives.

● The Internet of things typically conjures images of "smart" light bulbs and automatic door locks. Yet with an ever larger number of smart watches, activity trackers, and head-worn computers hitting the market, we're becoming part of the Internet of things, too.

Slowly but surely, a few wearable devices—mainly high-tech pedometers like those from Fitbit and Jawbone—are catching on with consumers, and many researchers and companies are certain that body-worn computers will become second nature—sensing, recording, and transmitting data to and from our bodies, to networks around us.

For the most part, wearables still lack wide appeal. Some, like Google Glass, elicit ambivalence. IDC estimates that manufacturers will ship 19 million watches, bands, and other wearables next year—barely a flicker next to the billion or so smartphones sold in 2013.

19 million
Number of watches, bands, and other wearables expected to ship in 2014

Wearables are still looking for their killer app. Now some people have begun to imagine that the Internet of things will provide it. If indeed our houses become filled with smart devices like door locks, a watch or wristband may be the most convenient way to control them or let them know our needs.

"Your car should know that you're tired because you didn't sleep that well, so it should be alert to that, how awake are you when you're driving, those things," says Hosain Rahman, the CEO of Jawbone, a 14-year-old company that makes earphones, speakers, as well as wrist-worn fitness trackers. "I just think that things that are on your body—wearables—ultimately will [control] all the smart stuff and be kind of at the center point."

Jawbone is among the first to try to turn a wearable into such a lifestyle remote. Jawbone's Up24 wristband can act as a trigger for the Web service IFTTT ("If This, Then That") by using its low-energy Bluetooth radio to share the data it gathers about you with an app on your smartphone. For now, it does only simple things. If you have an Internet-connected heater, the wristband can signal it to turn on when you get up in the morning. The idea is that the environment reacts to you.

Such ideas are in their infancy. Many companies are still struggling to get anyone to put a wearable computer on. Another problem is power. With Google Glass, for instance, you'll get a few hours of use before it needs to be recharged. And the biggest power draw is usually the wireless chip that lets these devices communicate. That's why MC10, a startup manufacturing soft, thin electronics, is experimenting with "every novel form of power source," says cofounder Ben Schlatka. One possibility comes from a project at Columbia University called Enhants. Researchers there are developing small, flexible tags that harvest energy from light or as they are shaken by movement. In an upcoming →

Wearable Wireless

Wireless electronic devices are gathering useful data about people.

OMSignal $240	OMShirt (gathers biometric data)
Jawbone $150	Up24 wireless wristband activity tracker
OMG Life $399	Autographer wearable camera
Google research stage	Glucose-sensing wireless contact lens
Proteus Biomedical research stage	Battery-powered drugs

SOURCE: MIT TECHNOLOGY REVIEW

research paper, they describe outfitting 40 people with flat sensors attached to different parts of their bodies while they walked, ran, or relaxed. Sensors were able to harvest enough energy to transmit data continuously at a rate of one kilobit per second. That's not much, but it could be enough for simple applications like authenticating someone's ID or reading the local temperature. Enhants researcher Peter Kinget, a professor of electrical engineering at Columbia, says enough energy can typically be harvested to wirelessly link a sensor on your body to a smartphone—something we're already comfortable carrying everywhere we go. —*Rachel Metz*

Emerged Technologies

Silicon Valley to Get a Cellular Network, Just for Things

A French company plans to build a wireless slow lane for small, low-power devices.

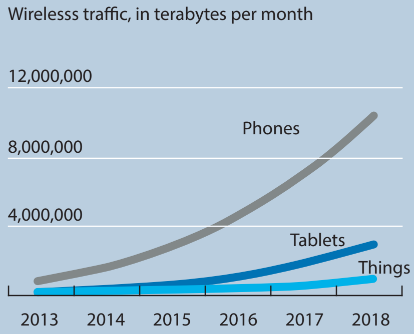
● San Francisco is set to get a new cellular network later this year, but it won't help fix the city's spotty mobile-phone coverage. This wireless network is exclusively for things.

The French company SigFox says it picked the Bay Area to demonstrate a wireless network intended to make it cheap and practical to link anything to the Internet, from smoke detectors to dog collars, bicycle locks, and water pipes.

Regular mobile networks are jammed with traffic from phone calls and people downloading videos. But for the Internet of things to become a reality, similar capabilities will need to be extended to billions of objects, many of them embedded in the environment and powered by small batteries. "If you want to get to billions of connections like that, you require a completely new type of network," says Luke D'Arcy, director of SigFox's operations in the U.S.

Global Wireless Boom

Devices that make up the Internet of things will compete for space on networks dominated by phones, games, and video.



SOURCE: CISCO VISUAL NETWORKING INDEX

SigFox's network will cover the San Francisco peninsula from its urban tip to the sprawling Silicon Valley region 40 miles to the south. It will be the company's first U.S. deployment of a network technology that already covers the whole of France, most of the Netherlands, and parts of Russia and Spain. SigFox built those by adding its own equipment to existing cell towers and radio antennas. Customers include the French insurance company MAAF, which offers smoke and motion detectors that notify homeowners with a text message on their phones when a sensor is triggered or needs a new battery.

The Silicon Valley network will use the unlicensed 915-megahertz spectrum band commonly used by cordless phones. Objects connected to SigFox's network can operate at very low power but will be able to transmit at only 100 bits per second—slower by a factor of 1,000 than the networks that serve smartphones. But that could be enough for many applications.

100 bits per second
Speed at which objects connected to SigFox's network can operate

Indeed, semiconductor companies like Intel and Broadcom are also in a race to make far cheaper, far smaller, and much-lower-power wireless chips. Several showed off these "miniature computers" at the Consumer Electronics Show this year. "They saw the cell phone turn into the smartphone, and so companies are saying 'What is next'?" says David Blaauw, a professor of engineering at the University of Michigan. Blaauw builds millimeter-scale wireless computers that he believes may one day report data from just about anywhere, even from inside a patient's tumor.

A SigFox base station can serve a radius of tens of kilometers in the countryside and five kilometers in urban areas. To connect to the network, a device will need a $1 or $2 wireless chip that's compatible, and customers will pay about $1 in service charges per year per device.

By reaching into the Bay Area first (with expansion to tech hubs such as Austin, Cambridge, and Boulder in its sights), SigFox hopes to catch the interest of a region where venture capitalists poured nearly $1 billion into startup companies focusing on the Internet of things last year, according to the research firm CB Insights. One of those startups, Whistle, makes a fitness-tracking collar for dogs. It has raised $6 million and is located in a corner of San Francisco that's been called "IoT Town" thanks to its profusion of similar ventures.

Ben Jacobs, Whistle's CEO, says the collar communicates by Bluetooth to a phone, or via a home Wi-Fi router. That limits what it can do. But a new version using SigFox's technology will have a constant Internet connection anywhere in town, letting it act as a beacon for lost pets. Previously, that would have required an expensive and power-hungry cellular phone on the collar.

SigFox is in a hurry to get its network in place before competitors arrive. Jacob Sharony, a principal at the wireless consultancy Mobius Consulting, says large wireless companies are preparing machine-only networks as well, and these may operate at much higher speeds. A new long-range, low-power Wi-Fi standard that has the backing of some major U.S. companies, including Qualcomm, could hit the market in 2016. "It will likely be a major contender even though it is somewhat late to the game," says Sharony.

—*Tom Simonite*

Industry Guide

The Internet of Things

Industry resources, key executives, and companies to watch.

Reports

Internet-of-Things Market, Value Networks, and Business Models: State of the Art Report

University of Jyväskylä, 2013
Oleksy Mazhelis, et al.

These Finnish computer scientists have organized many of the key data sets related to the Internet of things into a freely available report that is thick with detailed breakdowns of expected changes to Internet traffic and wireless protocols.

Industrial Internet: Pushing the Boundaries of Minds and Machines

General Electric, 2012
Peter C. Evans and Marco Annunziata

GE launched its push into the Internet of things with this white paper, which discusses potential economic savings if the “industrial Internet” leads to an efficiency gain of just 1 percent across industries.

Smart Everything: Will Intelligent Systems Reduce Resource Use?

Annual Review of Environment and Resources, 2013
Jonathan G. Koomey, H. Scot Matthews, and Eric Williams

For everything to be smart, everything needs a computer. And those computers will have to be powered. Stanford University energy specialist Jonathan Koomey and colleagues describe long-term trends that are leading to a “new class of computing device”—cheap, connected, and so low-power they can operate for long periods on batteries or even just with energy snatched from the environment.

Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2013–2018

Cisco Systems, 2013

There is already 18 times more mobile data traffic than there was traffic on the global Internet in 2000, and over half a billion new mobile devices were added to the network in 2013, mostly smartphones. The report predicts that by 2017, the number of networked devices will be three times the global population, and wireless devices such as tablets, TVs, and phones will account for 55 percent of Internet traffic.

Bell’s Law for the Birth and Death of Computer Classes: A Theory of the Computer’s Evolution

Microsoft, 2007
Gordon Bell

In this technical report, Microsoft researcher Gordon Bell describes the evolution since 1940 of widely used types of computers, arguing that new versions have consistently been 10 times more numerous than their predecessors at a tenth the price.

Books

Rethinking the Internet of Things: A Scalable Approach to Connecting Everything

Francis daCosta
Amazon Digital Services, 2013

This technical e-book describes an approach to extracting meaning from the billions of new data sources that are emerging as more computers communi-

Who We Are Following

James Chevalier	Founder, CityStrides	@TheIoT
Tom Coates’s house	Tweeting home, San Francisco	@houseofcoates
Beth Comstock	Chief marketing officer, GE	@bethcomstock
Alexandra Deschamps-Sonsino	Interaction designer, Designwarm	@iotwatch
Dave Evans	Chief futurist, Cisco Systems	@DaveTheFuturist
IBM Smarter Cities		@IBMSmartCities
Jeff Moad	Research director, *Manufacturing Executive*	@JM32
Christine Outram	Associate director of invention, Deutsche	@cityinnovation
Bill Ruh	Head, GE Software	@BillRuh_GE
SmartCities Platform	European Commission	@EUSmartCities
Anthony Townsend	Author, Smart Cities	@anthonymobile
Web of Things		@webofthings

cate on the Internet. The author asks what these simple new devices (a temperature sensor or rain gauge) will do and concludes that they'll mostly need to communicate very small amounts of information, or "chirps." He takes a contrarian view, arguing that they shouldn't be burdened with all the technology involved in the latest Internet protocol, IPv6.

The Zero Marginal Cost Society: The Internet of Things, the Collaborative Commons, and the Eclipse of Capitalism

Jeremy Rifkin
Palgrave Macmillan, 2014

This view from the political left is worth reading not because of the author's (often wrong) predictions about technology but because of what he wants from it. Examining some hot trends, like 3-D printing, sharing services such as Airbnb, driverless cars, and ubiquitous sensors, Rifkin concludes that capitalism will be replaced by a new "collaborative commons" in which energy and goods, just like information, will become nearly free. The result, he predicts, is that "capitalism will remain with us, albeit in an increasingly streamlined role."

Social Physics: How Good Ideas Spread—The Lessons from a New Science

Alex Pentland
Penguin Press, 2014

Dubbed the "presiding genius" of big data, MIT professor Alex "Sandy" Pentland describes a new science that he calls social physics—built by collecting and analyzing the digital crumbs we leave behind, particularly from our smartphones. Pentland expects to develop new insights into how people actually behave and what kinds of rewards motivate them. He even imagines mathematical models of civic behavior. His approach to studying human affairs by gathering digital traces, sometimes called reality mining, is the basis for numerous startup companies spun out from his lab.

Service Business Development: Strategies for Value Creation in Manufacturing Firms

Thomas Fischer, Heiko Gebauer, and Elgar Fleisch
Cambridge University Press, 2012

In this guidebook for manufacturers facing shrinking profits, Swiss academics summarize 12 years of research on how networks can let manufacturers create new services tied to their products.

Where We Are Going

W3C Workshop on the Web of Things
June 25–26, 2014
Siemensdamm 50
Berlin
www.w3.org/2014/02/wot

Machine2Machine Evolution Conference & Expo
August 11–14, 2014
The Rio
Las Vegas
www.m2mevolution.com

Shenzhen International Internet of Things Expo
August 14–16, 2014
Shenzhen Convention & Exhibition Center
Shenzhen, China
www.iotexpo.com.cn

Designers of Things
September 23–24, 2014
San Francisco
www.designersofthings.com/sanfrancisco/about

Internet of Things 2014
October 6–8, 2014
MIT
Cambridge, Massachusetts
www.iot-conference.org/iot2014

iOT360 and URB-IOT 2014: First International Conferences on IoT in Urban Space
October 27–28, 2014
Rome
http://iot-360.eu, http://urbaniot.org/2014/show/home

Executives to Watch

George Arnold

Director, Standards Coordination Office, and national coordinator, smart grid interoperability, National Institute of Standards and Technology
Gaithersburg, Maryland

On the Internet of things, standards and protocols will determine winners and losers. That makes George Arnold a quietly important player. As a smart-grid czar at the federal National Institute of Standards and Technology, Arnold is involved in setting standards for how digital technologies will affect the politically and strategically important electricity grid and other "cyber physical" systems. As part of an informal industry group known as the Kitchen Cabinet, Arnold was influential in establishing the commercial Industrial Internet Consortium this year. NIST's 2014 budget request included $18.8 million to study cyber-physical systems and their security. Arnold is a veteran of Bell Labs and the coauthor of one of the earliest examples of chess-playing software.

Gordon Bell

Researcher emeritus, Microsoft Research
Redmond, Washington

Back in the 1960s, Bell networked mainframe and minicomputers for Digital Equipment. Later he helped establish Microsoft's research lab and joined it in 1995. In 1998 he anticipated the quantified-self movement by starting an effort to record every e-mail, tens of thousands of photographs and phone recordings, all his computer use, and everything he owns, even while writing lengthy memoranda on Microsoft strategy in regard to network, smartphones, and the Internet of things. One prediction from 2007: "Tens of billions of dust-sized, embeddable wirelessly connected platforms that connect everything are likely to be the largest class of [computers] enabling the state of everything to be sensed, effected and communicated with."

Beth Comstock

Chief marketing officer, General Electric
Fairfield, Connecticut

Beth Comstock likes to call GE the "world's oldest startup." Her job is to make sure the 132-year-old company acts like a startup. As head of marketing, she oversees high-budget, high-concept campaigns like the "industrial Internet," GE's effort to invest in data analytics. She oversees GE Ventures, the company's in-house venture capital shop, as well as efforts to stir up innovation through open competitions partnering with startups.

Tony Fadell

Founder and CEO, Nest
Palo Alto, California

Tony Fadell created the first recognizable consumer brand of the Internet of things, the Nest Learning Thermostat. Formerly a designer and executive at Apple, Fadell created the first 18 versions of the iPod under Steve Jobs. In 2008 he left Apple and created a true garage startup to replace the $29 "beige box" thermostat with a $249 version capable of collecting detailed information about what goes on inside a house. Consumers cheered; sales topped 50,000 units a month by early 2013. When Google bought his company in 2014 for $3.2 billion, it was partly to get hold of Fadell and his skills in consumer gadget design, notably lacking at Google. Fadell, a computer engineer, holds over 300 patents.

William Ruh

Vice president and global technology director, General Electric
San Ramon, California

When GE needed to fix its sprawling software operations, it needed a big name. It picked Bill Ruh, a well-established software executive from Cisco. Around GE, Ruh's name is uttered with reverence. He's taken on the job of organizing GE's software operations, which, though scattered, do $4 billion in sales and employ about 10,000 people (as many as work at Adobe). That takes a technical vision. Ruh's has been to create a new software and R&D center in San Ramon to centralize GE's efforts. Since he joined in 2011, GE has created Predix, a standard system for doing analytics on industrial data that GE says has generated more than $800 million in new sales.

Companies to Watch

Apigee

Founded: 2004
San Jose, CA
Vital statistic: $173 million in funding from Norwest Venture Partners, Bay Partners, SAP Ventures, and Third Point

Apigee helps develop mobile apps and application programming interfaces, or APIs, for big companies that want to open up their data streams for the world to plug into, just as Facebook or Twitter do. Helping big companies "master the art and science" of the app economy will matter as these companies try to turn light bulbs and automobiles into information technology platforms and business ecosystems. Apigee is to carry out an IPO in 2014.

Broadcom

Founded: 1991
Irvine, California
Vital statistic: $8.3 billion in revenue

You may not have heard of Broadcom, but crack open any Internet of things device, like the MyQ garage door opener or a Honeywell smart thermostat, and you're likely to find a Broadcom wireless chip inside. The chip maker says 99 percent of Internet traffic passes through its products, which are also found in set-top boxes, smartphones, and routers. Unlike Intel but like chip makers such as Texas Instruments, Broadcom is targeting the low end of the market, which is expected to grow quickly as more products require cheap connectivity. To capture this market, in 2013 Broadcom introduced a "turnkey" system, called WICED (consisting of a small processor and Wi-Fi chip), that device manufacturers can embed into objects to make them into wireless nodes.

Cisco Systems

Founded: 1984
San Jose, California
Vital statistics: $48.6 billion in annual sales and 75,000 employees

Cisco is one of the loudest cheerleaders for the Internet of things. No wonder. Every time someone connects a new device to the Internet, Cisco stands to make more money selling switches, routers, and Wi-Fi equipment. "The more devices there are, the better for us," said a Cisco executive. By Cisco's estimate, only 4 percent of devices on factory floors are connected to the Internet. In the next seven years, Cisco estimates, 27 billion devices will be connected to a network, mostly machines like solar panels, engines, and trucks.

Electric Imp

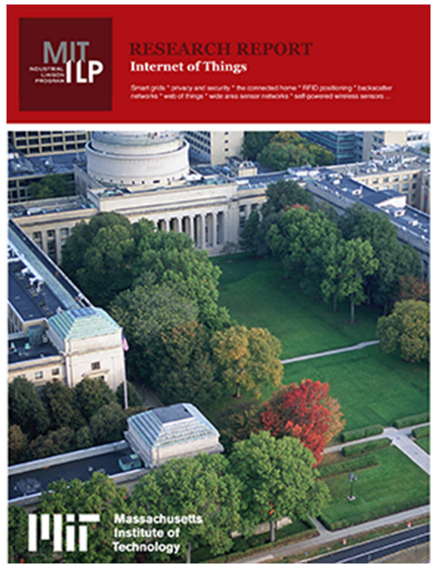
Founded: 2011
Los Altos, California
Vital statistic: Raised $8 million from Redpoint Ventures and Lowercase Capital, among others

How do objects get connected to the Internet? One new option is the Imp, a system developed by former iPhone engineer Hugo Fiennes that makes it relatively easy to "Internet-enable" any product. The Imp is a small computer with a processor and wireless Wi-Fi chip; then there's software to program the Imp and run it from the Internet. The Imp is becoming a favored test bed for gadgeteers and

MIT RESEARCH

The Internet of Things

The following is a sample of MIT research in areas related to the Internet of Things. A full ILP Research Report on the topic is available upon request by clicking the following link or by emailing egan@ilp.mit.edu.



Request ILP Research Report

- THE INTERNET OF THINGS - 44 pages (PDF)

Programs / Initiatives

City Science

http://cities.media.mit.edu/about/cities

The world is experiencing a period of extreme urbanization. In China alone, 300 million rural inhabitants will move to urban areas over the next 15 years. This will require building an infrastructure equivalent to the one housing the entire population of the United States in a matter of a few decades.

In the future, cities will account for nearly 90% of global population growth, 80% of wealth creation, and 60% of total energy consumption. Developing better strategies for the creation of new cities is, therefore, a global imperative.

The need to improve our understanding of cities, however, is pressed not only by the social relevance of urban environments but also by the availability of new strategies for city-scale interventions that are enabled by emerging technologies. Leveraging advances in data analysis, sensor technologies, and urban experiments, City Science will provide new insights into creating a data-driven approach to urban design and planning. To build the cities that the world needs, a scientific understanding of cities that considers our built environments and the people who inhabit them is needed. Future cities will desperately need such understanding.

Building on current work at the MIT Media Lab, City Science researchers will initially focus on the following project themes. Additional project themes will be added in response to the priorities of corporate members, MIT researchers, and the City Science advisory board. These six initial themes represent a cross section of the interdisciplinary research that will be undertaken to address the major challenges associated with global urbanization.

Mobility networks: Projects in this theme include the development of a sophisticated multi-modal mobility recommendation engine that ties together a variety of modes, from carpooling to bike sharing, and is influenced by real-time data such as weather patterns, traffic, and past user behavior. New urban vehicles including electric scooters, cars, and compact bike-lane vehicles are being designed and prototyped at the MIT Media Lab. Existing vehicle prototypes and vehicle-pedestrian interfaces for autonomous cars can offer a powerful platform for user-centric autonomous vehicle research. Improved public infrastructure for shared electric vehicles such as integrated charging and locking technology will reduce vehicle rental/drop-off time and dramatically improve user experience. Similarly, persuasive interfaces for shared-use vehicle systems can encourage mode-shift and positive mobility patterns for health.

http://cities.media.mit.edu/research/mobility-networks

Places of living and work: The nature of work is changing dramatically with the ubiquity of mobile devices and Internet connectivity. The traditional office building is rapidly becoming obsolete as a place for personal work. Boundaries between home and the workplace are dissolving rapidly, spurred by advanced computation and synchronous and asynchronous communication. The design and prototyping of personalized, transformable urban housing will enable city dwellers to maximize the functionality of a small apartment, thereby improving livability and convenience. Time-shifted, shared space-on-demand for collaborative work will allow for face-to-face meetings while giving businesses the opportunity to reduce their office space requirements and reduce net energy consumption. The integration of modular, personalized hydroponic and aeroponic urban farming systems will give urban residents the opportunity to grow their own food and improve transparency of our incredibly complex food supply chain.

http://cities.media.mit.edu/research/places-of-living

Electronic & social networks: Projects in this theme will explore electronic nervous systems, from the scale of the human body to the city. These decentralized electronic and social networks can form the basis for new patterns of learning, recreation, production, and health. They can provide pathways for people to communicate with their private and public worlds. To reach its full potential, an interlinked system of trust networks, that provide security through data encryption and biometric technologies, must be developed. These trust networks ensure privacy for otherwise invasive systems that make use of highly personal data such as mobility patterns, resource consumption (food, water, energy), and individualized health profiles.

http://cities.media.mit.edu/research/electronic-social-networks

Energy networks: New technologies for smart grids and intelligent metering can enable urban energy networks that dynamically respond to human mobility and behavior patterns. Today, networked demand response systems can reduce peak loading on our aging electric grids but the integration of renewable energy sources is still difficult due to intermittency. Projects in this theme will focus on the exploration of DC microgrids for compact urban cells that incorporate localized renewable energy generation sources such as rooftop solar and microturbines. These local DC power networks can reduce AC/DC conversion losses in residential buildings and provide direct connections to photovoltaic energy and battery-based energy storage. New technologies for energy storage will be investigated in depth, including business and service models for repurposing second-life automobile batteries for grid energy storage and buffering rapid charging of electric vehicles.

http://cities.media.mit.edu/research/energy-networks

Urban analytics: Urban Analytics focuses on data-driven analyses of economic activity, urban perception, human behavior, mobility patterns, and resource consumption to inform the city design process. Parametric urban design tools and computer simulations will enable the creation of rapid prototyping tools for the placement of mobility nodes, street typologies, and resource allocation. Targeted interventions for existing cities and phasing strategies for the development of new cities will be generated in an evidence-based fashion, influenced by the findings of living laboratory experiments, and sophisticated data analysis.

http://cities.media.mit.edu/research/urban-analysis

Incentives & governance: Projects in this theme will address the creation of new, network-centric methods for managing reactive urban systems. This includes the prototyping of persuasive interfaces that provide dynamic incentives for rebalancing of shared-use systems, and replacing the traditional one-size-fits-all urban service strategy with flexible options. These new models will be influenced by crowd-sourced intelligence and respond in real-time to the needs of urban residents. Urban-scale serious games can provide targeted incentives for city dwellers to alter their consumption patterns and shape use of resources such as shared-used mobility, variable-rate electricity, and flexible/time-shared workspaces. New portals for information dissemination through mobile applications and web-based interfaces will improve transparency in governance and accessibility of information.

http://cities.media.mit.edu/research/incentives-and-governance

Cloud of Things

Prof. Sanjay E Sarma,
http://meche.mit.edu/people/?id=74

Auto-ID Labs' (http://www.autoid-labs.org/) launched "Cloud of Things" initiative joins several ongoing projects at the Auto-ID Labs to connect physical objects — such as vehicles and buildings — to the cloud.

The "Cloud of Things" builds on the "Internet of Things" (a term coined at the MIT Auto-ID Labs), where information about objects is accessed via the Internet and machine-to-machine (M2M) computing, where wireless communication protocols enable peer-to-peer exchange of data between electronic devices. Constructing a model of an object in the cloud with a defined set of Application Programming Interfaces (APIs) facilitates the integration of data from heterogeneous sources more readily than trying to establish a common registry or protocol across multiple organizations.

The "Cloud of Things" initiative will bring together researchers and industry to design sponsored-research initiatives for specific companies and industries; it will also host a series of theme-focused workshops, conferences, panels, demonstrations, exhibits and pilots on various topics. Particular areas of focus will include manufacturing, retail, health care, supply chain and more. The initiative is open to companies, nonprofits, and individuals interested in promoting the development, adoption and commercial success of big data applications.

The MIT Auto-ID Laboratory is dedicated to creating the Internet of Things using RFID and Wireless Sensor Networks. The aim from the start was to create a global system for tracking goods using a single numbering system called the Electronic Product Code. The Auto-ID Labs are the leading global network of academic research laboratories in the field of networked RFID. The labs comprise seven of the world's most renowned research universities located on four different continents.

http://newsoffice.mit.edu/2012/auto-id-cloud-of-things-big-data

Labs, Centers, Groups

Center for Environmental Sensing And Modeling (CENSAM)

http://censam.mit.edu/about/index.html

The Center for Environmental Sensing And Modeling (CENSAM), a Singapore-MIT Alliance for Research and Technology (SMART) - Interdisciplinary Research Group (IRG), seeks to provide proof of concepts in the paradigm of pervasive monitoring, modeling and control within the highly developed and carefully managed urban environment of Singapore.

Working together, MIT and Singapore collaborators are establishing capabilities within CENSAM and in Singapore academic institutions to address environmental problems of importance to Singapore and South East Asia.

Urban research includes the thermal coupling between buildings and urban atmosphere that produces the urban heat island effect, investigations of urban air and water quality, and the development of wireless sensor networks to monitor and control urban systems.

Marine investigations include coastal sediment transport and the development of fully automated chemical sensing systems for deployment in autonomous marine vehicles, which incorporate elements of biomimicry and have advanced navigational and mapping facilities.

Climate studies include predictions of regional climate change at decadal time scales, field-based investigations of tropical peat lands and carbon emissions associated with their destruction, and paleoclimate investigations based on corals that act as long-term sensors of chemical changes in the marine environment.

CENSAM's goals are to develop and deploy new environmental sensor technologies and to incorporate data from these and other sources into representations of the natural and built environment that are linked across spatial scales, from an individual constructed facility to the meso-scale of the city-state, the regional ocean and atmosphere and the global climate.

Resilient Infrastructure Networks Lab

Prof. Saurabh Amin,
http://cee.mit.edu/amin

The group designs and implements network control algorithms for infrastructure systems, with the emphasis on survivability in uncertain and adversarial conditions. Specifically, the group focuses on monitoring and control of energy, transportation, and water distribution infrastructures.

Robust Infrastructure Diagnostics and Control: Networked control systems (NCS) can be viewed as a set of networked agents consisting of sensors, actuators, computational units, and communication devices. NCS are increasingly deployed to facilitate real-time monitoring and control of large-scale critical infrastructures. The group is specifically interested in NCS for energy, transportation, and water distribution infrastructures. The goal is to develop (i) model-based tools for incident detection and fault/attack diagnosis; (ii) network control algorithms for closed-loop stability and robustness; (iii) adaptive mechanisms for NCS reconfiguration in the presence of extreme disturbances. The researchers believe that these control specific detection and response mechanisms will increase the infrastructures' survivability and reduce risks of cascading failures.

Testbed for Networked Control Systems: A testbed to study the effect of correlated hardware malfunctions and software flaws on the survivability of networked control systems is being developed by the group. The testbed capabilities will include: (i) reconfigurable and computationally efficient implementations of diagnostic tools and control methods; (ii) emulations and simulations of control system components; and (iii) experiments for humans and hardware in the loop. The group will use a multi-scale approach to integrate strategic decision making with operational execution of robust control strategies. This flexible and powerful cyber-physical experimental facility will be made available to the larger research community.

See more at: http://resil.mit.edu/projects

W3C: Web of Things Community Group (CG)

http://www.w3.org/community/about/

The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. Led by Web inventor Tim Berners-Lee and CEO Jeffrey Jaffe, W3C's mission is to lead the Web to its full potential. http://www.w3.org/

The aim of the Web of Things Community Group (CG) is to accelerate the adoption of Web technologies as a basis for enabling services for the combination of the Internet of Things with rich descriptions of things and the context in which they are used.

http://www.w3.org/community/wot/

Projects

BUZZ: Efficient and Reliable Low-Power Backscatter Networks

Profs. Dina Katabi and Piotr Indyk
Grad Students: Haitham Al Hassanieh and Jue Wang

There is a long-standing vision of embedding backscatter nodes like RFIDs into everyday objects to build ultralow power ubiquitous networks. A major problem that has challenged this vision is that backscatter communication is neither reliable nor efficient. Backscatter nodes cannot sense each other, and hence tend to suffer from colliding transmissions. Further, they are ineffective at adapting the bit rate to channel conditions, and thus miss opportunities to increase throughput, or transmit above capacity causing errors....

http://groups.csail.mit.edu/netmit/wordpress/projects/low-power-networks/buzz/

http://wireless.csail.mit.edu/node/54

Minimizing Energy for Communications in Medical Body Area Networks

Medical Electronic Device Realization Center (MEDRC)
Prof. Charles Sodini

In recently published integrated medical monitoring systems, a common thread is the high power consumption of the radio compared to the other system components. Narrowband receivers in-particular enjoy significant power reduction by employing high-Q bulk acoustic resonators as channel select filters directly at RF, allowing down-stream analog processing to be simplified, and resulting in better energy efficiency, however, the high-Q nature of the resonators means that frequency tuning to other channels in the same band is nearly impossible. In this work, a three-channel ultra-low power 2.4GHz OOK receiver for Body Area Networks (BANs) has been designed and tested in 65nm CMOS. The receiver uses Film Bulk Acoustic Resonators (FBARs) to enable multiple sub-channels of operation within a band at a very low energy per received bit. The receive chain features an LNA/mixer architecture that efficiently multiplexes the resonators without degrading their quality factor. The single-balanced mixer and ultra-low power ring oscillator convert the signal to IF, where it is efficiently amplified to enable envelope detection. The measured BER=10−3 sensitivity is −67dBm at 1Mbps for an energy efficiency of 180 pJ/bit. The resonators are packaged beside the CMOS using wirebonds for the prototype, but future technologies may one day allow the resonators to be integrated onto the silicon.

http://medrc.mit.edu/services/minimizing-energy-for-communications-in-medical-body-area-networks/

Sustainable Networks: From Smart Grids to Green Robust Information Networks

Prof. Eytan Modiano
http://web.mit.edu/aeroastro/sites/modiano/

MIT & Masdar Institute Collaborative Research
http://web.mit.edu/mit-mi-cp/research/projects/power03.html

Smart grids, integrating electrical power networks and information networks, are a new paradigm for future energy systems. Only limited studies have looked at the interplay between electrical power networks and information networks. In this research, we carry out a comprehensive study to understand the interdependence between electrical power networks and information networks in smart grids.

The information networking perspective to energy networks is a key component required for low-carbon economic development and energy efficiency. There are vibrant related ongoing research activities in Masdar Institute and Masdar City that are complementary to this research.

TagMe: An Easy-to-Use Toolkit for Turning the Personal Environment Into an Extended Communications Interface

Prof. Pattie Maes,
http://web.media.mit.edu/~pattie/

Fluid Interfaces Group,
http://fluid.media.mit.edu/projects/tagme

TagMe is an end-user toolkit for easy creation of responsive objects and environments. It consists of a wearable device that recognizes the object or surface the user is touching. The user can make everyday objects come to life through the use of RFID tag stickers, which are read by an RFID bracelet whenever the user touches the object. We present a novel approach to create simple and customizable rules based on emotional attachment to objects and social interactions of people. Using this simple technology, the user can extend their application interfaces to include physical objects and surfaces into their personal environment, allowing people to communicate through everyday objects in very low-effort ways.

"TagMe: An Easy-to-Use Toolkit for Turning the Personal Environment into an Extended Communications Interface."

Xavier Benavides, Judith Amores, Pattie Maes. ACM Intl. Conf. Human Factors in Computing (CHI 2014), Work-In-Progress (2014).

Books

Enchanted Objects: Design, Human Desire, and the Internet of Things

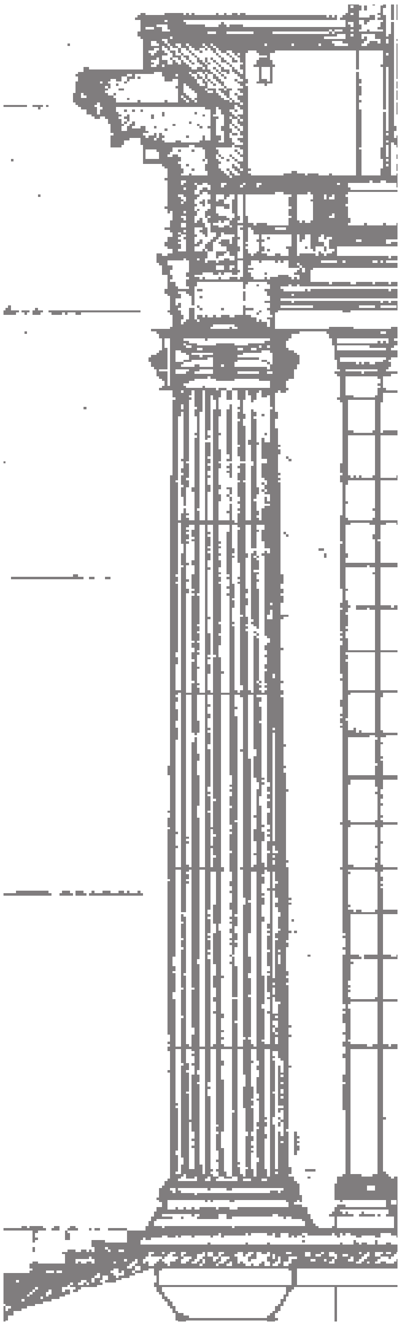
By David Rose, Simon & Schuster Books, July 2014
http://books.simonandschuster.com/Enchanted-Objects/David-Rose/9781476725635

In the tradition of *Who Owns the Future?* and *The Second Machine Age*, an MIT Media Lab scientist imagines how everyday objects can intuit our needs and improve our lives.

We are now standing at the precipice of the next transformative development: the Internet of Things. Soon, connected technology will be embedded in hundreds of everyday objects we already use: our cars, wallets, watches, umbrellas, even our trashcans. These objects will respond to our needs, come to know us, and learn to think on our behalf. David Rose calls these devices—which are just beginning to creep into the marketplace—Enchanted Objects.

Some believe the future will look like more of the same—more smartphones, tablets, screens embedded in every conceivable surface. Rose has a different vision: technology that atomizes, combining itself with the objects that make up the very fabric of daily living. Such technology will be woven into the background of our

Technology & The Corporation
Conference Series



2014-2015

2014 The Second Machine Age Conference
September 10-11, 2014
MIT Campus

2014 MIT Materials Day
October 21, 2014
MIT Campus

2014 MIT Innovation Conference
October 28-29, 2014
MIT Campus

2014 MIT Research & Development Conference
November 19-20, 2014
MIT Campus

2015 MIT Japan Conference
January 23, 2015
Tokyo, Japan

2015 MIT Europe Conference in Vienna
March 25-26, 2015
Vienna, Austria

2015 MIT Information and Communication Technologies Conference
April 29-30, 2015
MIT Campus

2015 MIT Brazil Conference
May 12-14, 2015
São Paulo, Brazil

2015 MIT China Conference
May 22-23, 2015
Wuxi, China

environment, enhancing human relationships and channeling desires for omniscience, long life, and creative expression. The enchanted objects of fairy tales and science fiction will enter real life.

Groundbreaking, timely, and provocative, *Enchanted Objects* is a blueprint for a better future, where efficient solutions come hand in hand with technology that delights our senses. It is essential reading for designers, technologists, entrepreneurs, business leaders, and anyone who wishes to understand the future and stay relevant in the Internet of Things.

Author: David Rose, Visiting Scientist, Tangible Media Group, MIT Media Lab, http://tangible.media.mit.edu/person/david-rose/

ILP RESOURCES

KnowledgeBase

http://ilp.mit.edu/expertise.jsp

The ILP KnowledgeBase is an actively-maintained database of information about MIT faculty, research projects, publications, and departments, labs, and centers ("DLCs and Research Staff"). This database is provided as a service to the corporate members of the Industrial Liaison Program, as well as to the MIT community. For full access, sign in as an ILP member or use your MIT certificate.

Video Archive

http://ilp.mit.edu/video.jsp

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