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ACTIVATING THE INTERNET OF THINGS

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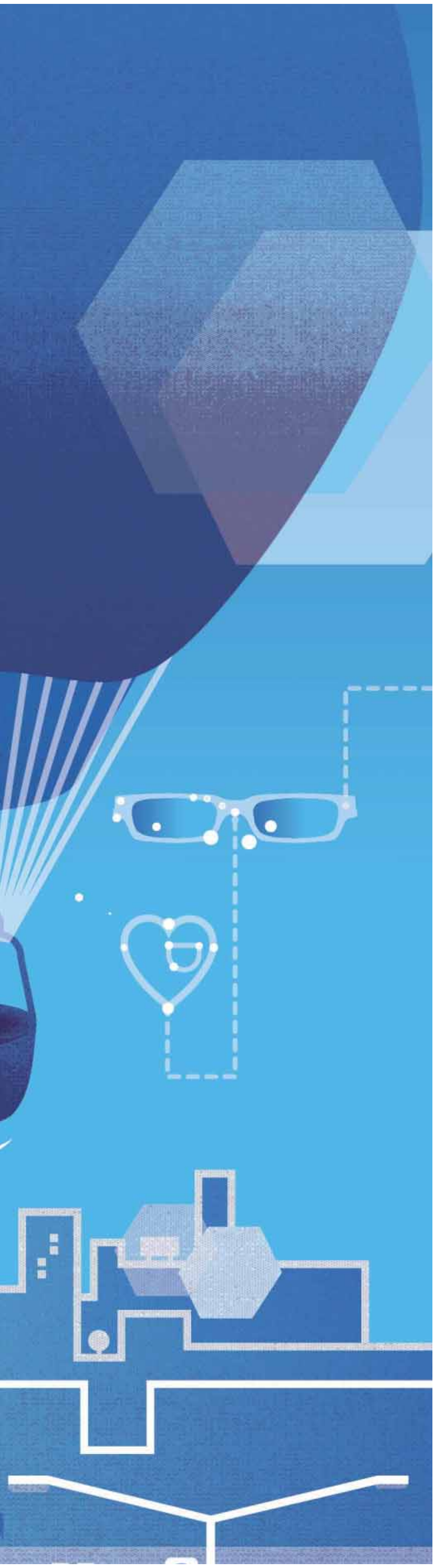

Now is the time to tune in, turn on, and plug in—the Internet of Things ushers in a whole new paradigm in our relationship with technology.

The Internet of Things (IoT) is a term now widely used in scholarly technical publications and mainstream media. CEOs of major tech companies center their keynote addresses around this term at top industry shows—as illustrated by Samsung CEO BK Yoon's address at this year's Consumer Electronics Show.

What is so exciting about the IoT? What does it really mean and why should we care? The IoT vision, simply put, is that almost any electronic device can be augmented by a connection to the Internet, enabling an ordinary standalone device to become a smart networked device.[1] For example, a garden sprinkler system can carry out its watering task more efficiently if it knows the weather forecast or the moisture needs of the plants it waters. Likewise, an air conditioning unit can reduce running costs if it knows when the cheapest off-peak electricity is available. All manner of devices can use Internet-derived information to improve their basic operation and become smarter, more efficient, and cost-effective.[2]

In some cases, this means a *thing* becomes a first-class network computer with an IP address, as accessible as any other networked computer. However, the IoT's scope also includes devices that are only occasionally available on the network to save power, or are connected via a proxy device such as a passing smartphone. In the latter case, a device can use protocols such as Bluetooth low energy (BLE) to connect to the smartphone, which in turn uses an LTE cellular service to connect to the Internet and ultimately to a cloud service. However, the common factor for all IoT devices—from low-end sensors to high-end appliances—is that they will have some form of Internet connectivity and embedded processing to make use of it.

Analysts have predicted the IoT to be the "next big thing" for several years. Gartner recently estimated that there would be about 5 billion devices connected to the Internet in 2015, rising to 25 billion by 2020.[3] Others see the IoT as just another overhyped tech story feeding headlines and giving consumers inflated expectations. However, even if only half the predicted number of things come online, these numbers are so large that it will still be a significant evolution of the Internet.

So, why are IoT expectations increasing so rapidly today and not 10 years ago? Part of the answer is that many of the devices not yet connected to the Internet tend to be low-cost devices built for just one purpose. Thus, the overhead of integrating Internet connectivity—via a cable or wireless solution—for these devices would have been cost prohibitive for manufacturers. Since then, broadband Internet connectivity has become ubiquitous and available to the majority of homes in the developed world. This is often further augmented with Wi-Fi access points, enabling IoT devices to be easily deployed and connected to cloud services. And because almost everyone carries a smartphone—with a high-bandwidth cellular Internet connection such as LTE in addition to local Wi-Fi and Bluetooth access—we can each serve as a bridge for data that flows from an IoT device 30 feet away to the Internet. At present, there are about 2 billion smartphones in use—that is a lot of opportunities for an IoT bridging capability.

Moreover, technology development has marched on, as predicted by Moore's law, resulting in dramatic increases in processor performance and memory capacity over the past 10 to 15 years. As a result of lithographic scaling for VLSI, the average energy consumed per processor instruction has also decreased. Combined, these factors have enabled products to transition from low-end 8-bit microprocessors to 32-bit systems capable of supporting complete operating systems and fully functional network protocol stacks—cheaply and in battery-operated mobile devices. As a result, these embedded systems behave like the desktop computers of 10 years ago, and they are easily integrated with low-end appliances. With very little additional cost, such appliances can add a network interface and take full advantage of Internet connectivity.

As with any new technology, the IoT brings an improved standard of living, better ways of doing things, and increased productivity. However, such changes often result in social challenges.

IoT OPPORTUNITIES

A vision of the future in which our devices become smarter by anticipating our wants and needs and respond accordingly seems to depend quite heavily on a successful IoT design. We see three key areas in which the IoT has the most to offer: composable systems, smart cities, and more efficient use of resources.

Composable systems

Because the IoT allows us to make connections among many different kinds of devices, we can build new ad hoc systems from a variety of nearby things. As these devices discover one another over local wireless connections, they can present users with options for combining resources to provide higher-level capabilities. Like Web service mashups, in which a single webpage can provide a utility built on top of a collection of Web services, these composable systems provide more value as a whole than the simple sum of their component parts.

For example, imagine a logical computer being assembled on the fly using nearby devices to provide a powerful computing experience—without a traditional physical computer. Such a system could be assembled from a collection of colocated devices: a smartphone, a full-size keyboard, and a digital TV. The smartphone would serve as the computing hub, extending its screen wirelessly to the digital TV and providing improved user interaction through the full-size keyboard. Because these connections are all wireless, the components can easily be reconfigured using different combinations of nearby devices. Thus, in principle, composable systems can be rapidly adapted to the task at hand.

Smart cities

A modern city provides many essential utilities that are not necessarily managed in the most efficient way. For example, a city's traffic-light network is composed of a collection of simple timers to control the signals, and there is surprisingly little consideration of the presence of cars and efficient road utilization. Consider a scenario in which you are driving through a business district late at night. You stop at each red light, even though there is very little traffic on the cross streets. This wastes time as well as the energy required to stop and start the vehicle. Thus, a traffic-light system capable of sensing the location and density of cars in the area could optimize when the lights turn red or green throughout the day, and provide the best possible service for drivers, pedestrians, and the city.

Conservation of resources

Applicable across many IoT devices and applications, resource conservation offers a significant benefit. The extensive use of Internet-connected networked sensors—both wired and wireless—allows for vast improvements in the monitoring and optimization of resources such as electricity and water. Examples include powering off lights in a room when it is empty, and monitoring the weather and gauging appropriate irrigation. Many of the utilities we use on a daily basis run in open-loop mode—that is, resources are provided without any direct feedback about their aggregate use or the resulting cost. Closing the sensing loop to provide smart control for more efficient use of resources is one of the IoT's biggest potential societal benefits.

IoT CHALLENGES

The IoT presents some key risks, too. With so many interconnected things, boundaries disappear or become difficult to establish and defend. As systems become more intertwined, interdependent, and sophisticated, their

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weaknesses become more significant. In critical systems, any sort of interruption or corruption could result in property damage or, in the worst case, loss of life. But even more immediate are concerns about security, privacy, and standardization of user interfaces.

Security

IoT data from smart things and sensors capturing resource use can be collected and processed with the intent of improving our daily lives. Although city utility managers and business owners are generally trusted and believed to use the information as intended, there is always a risk that the data could end up in the wrong hands and be used for nefarious purposes. For example, although real-time energy monitoring helps indicate when consumption is above average or when appliances could operate more efficiently, the same data might also be intercepted and reveal when you are away from home for an extended period, making your house a good target for burglary.

Privacy

Communications among smart devices could also reveal private information about you. If you carry a smart device that talks to another device at a particular location, the communication between these two devices can be used to infer your presence. In other words, you can be tracked from place to place. Although identity is usually not revealed directly in the form of a name, a recurring network identifier such as a network MAC address can provide the association. Moreover, most people live at a fixed address they return to each evening, and this address can be easily linked with a person's name. Therefore, as you continue to use your smart device at home with other networked devices, you could inadvertently link your name with the MAC address, thereby also potentially revealing your location history. Although the solution to this particular problem is to obfuscate wireless MAC addresses by randomly changing the associated numbers while in use, there are many other types of device information that can lead to identity inference, and for some data the solution is not as clear-cut.

User interface standardization

The WIMP (Windows, Icons, Mouse, Pointer) interface has become the dominant paradigm for desktop computers, so if you are familiar with one computer type, you can walk up to almost any other computer and be able to use it effectively. However, IoT devices come in a variety of sizes and shapes, and their user interfaces are just as varied. Although standardization will eventually come to IoT devices, there will be a period of evolution that could lead to some confusion. Consider, for example, media player controls and their symbols: play, record, pause, stop, fast-forward, and rewind. When these controls were first developed, a variety of words and symbols were used by consumer electronics vendors and it took several years to converge on the standard set we use today. Standards organizations can help move this along—given how long convergence can take, it makes sense to encourage early standardization of IoT symbology wherever possible.

IN THIS ISSUE

For this special issue on activating the IoT, we selected three articles that look at the overall engineering and design strategies that help realize some of this technology's opportunities and will advance its implementation.

The first article we selected for this issue, "Aggregate Programming for the Internet of Things," by Jacob Beal, Danilo Pianini, and Mirko Viroli, explores how to program the IoT at higher levels of abstraction. Embedded IoT devices are very difficult to effectively coordinate using traditional programming methods. This is because of challenges relating to bringing together large numbers of devices at high densities, and the tight coupling between functionality and spatial proximity of the IoT devices. The authors introduce a framework based on field calculus constructs and building-block APIs, an engineering approach to programming that will help unlock the IoT's potential.

In the second article, "Design and Deployment of an IoT Application-

Oriented Testbed," Laura Belli, Simone Cirani, Luca Davoli, Andrea Gorrieri, Mirko Mancin, Marco Picone, and Gianluigi Ferrari present a method for providing a stable, open, and evolving infrastructure to be used as the basis for future IoT application development. The authors describe a testbed consisting of more than 50 nodes, which includes some significant development features including service discovery, human interactivity, user localization, and security.

In the final article, "Repurposing Web Analytics to Support the IoT," Mateusz Mikusz, Sarah Clinch, Rachel Jones, Mike Harding, Christopher Winstanley, and Nigel Davies report on their experience of creating and using a new system that repurposes Web analytics to enable growth of the future IoT. Web analytics are widely regarded by developers and business analysts alike to have a catalytic effect on the growth of the Web for commerce, and IoT analytics could have a similar effect. The authors detail a cloud-based mapping service that can translate IoT events into corresponding Web-based analytics events, and they give four detailed examples that illustrate the use of this service.

This is the Internet age, and we are at a particularly exciting point in which large numbers of devices are joining the network and helping to drive breakthrough innovation in applications and services. To quote Metcalfe's law, "the value of a telecommunications network is proportional to the square of the number of connected users of the system." Thus, if we increase the number of connected devices by 10- to 100-fold, the number of new users and the ultimate value of the network will soar.

We hope you enjoy reading the articles in this special issue, and that they both shed light on and inspire new ideas and innovations, further activating the IoT. **C**

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