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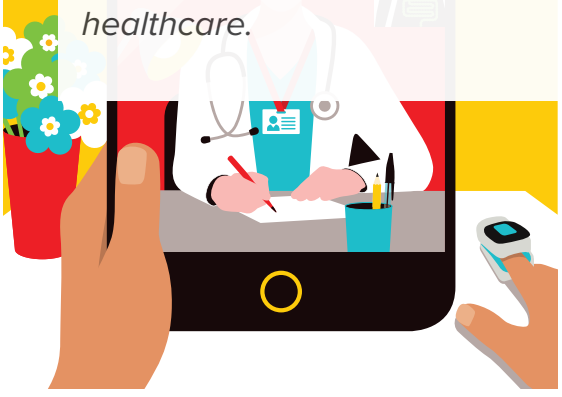

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The Rise of Hardware Security in Computer Architectures

Patrick Schaumont, Virginia Polytechnic Institute and State University
Paolo Montuschi, Polytechnic University of Turin

This installment of Computer's *series highlighting the work published in IEEE Computer Society journals comes from* IEEE Transactions on Computers.

Computing systems have become truly pervasive, up to serving as alter-egos for their human owners. They control critical aspects of our life and act as data repositories for everything important to us. And this trend is only accelerating: smart assistants tend to our every need—from turning on the television to ordering groceries—and in the cloud, data aggregation leads to improved analysis and, ultimately, decisions that benefit both society and the individual.

These exciting computing innovations have spawned equally exciting technical problems. The research community has already made great strides toward low power and energy, increased reliability, usability, and performance. Among the technical factors, security still stands out as a top priority. Security's basic issues are well known: How can we protect personal user data? How can we protect user privacy? How can we guarantee fair and consistent service of computing resources to their users? The recently introduced General Data Protection Regulation (GDPR; www.eugdpr.org) is dramatically changing the scenario by clearly stating roles, rules, and responsibilities. It's now a matter of fact that we need (certified) secure computing systems.

A fundamental principle of execution in computer architectures is to keep applications isolated from each other and the underlying software environment and operating systems. That isolation is provided though hardware-supported techniques such as privilege levels, virtual memory, sandboxes, and secure containers. In practical architectures, the isolation is virtual, and doesn't extend into the computer hardware. Hence, software applications still share the same physical memory chips, processor, and communication buses.

Computer security is built on the isolation provided by computer architectures. Indeed, the best way to maintain confidentiality and integrity of an application's secure data is to ensure that the data is unreachable by anyone but the application itself. To understand how effective isolation is in its support of computer security, one must consider the attacker's abilities, or the *attacker model*.

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EDITOR **RON VETTER**
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We distinguish three attacker models, but current computer isolation techniques are only effective against two of them (see Figure 1). The first model, the input/output attacker, is based on manipulation of the input data to the application. This attacker is responsible for a vast body of computer exploits, including, for example, stack buffer overflows and cross-site scripting attacks. The second model, the memory attacker, coexists in the same physical memory space as the secure application. This attacker aims to snoop or manipulate directly into the memory space of the application. The third model, the hardware attacker, can observe and manipulate the physics of the computations performed in hardware. This attacker exploits side-channel leakage or intentional fault injection to circumvent privileges and isolation boundaries in the hardware.

The hardware attacker model is an enormous challenge to the future of computer security. Computer architectures have traditionally been developed using logical abstractions, and are optimized to execute software applications as quickly and as efficiently as possible.

They deploy a wide array of techniques to make the most likely case execute the fastest. These techniques might include cache memory, memory hierarchies, branch prediction, and translation lookaside buffers. All of these optimization techniques are transparent to the input/output attacker model and the memory attacker model. However, they are visible to the hardware attacker, and have become the source of a novel family of attacks, including the Meltdown and Spectre attacks disclosed earlier this year.

IEEE Transactions on Computers (TC) is committed to publishing the latest research on innovations and countermeasures in hardware security within the context of secure computer architectures. A 2018 special section collected recent results and findings in this field. Dealing with the hardware attacker will require revisiting some of the basic design assumptions in the field.

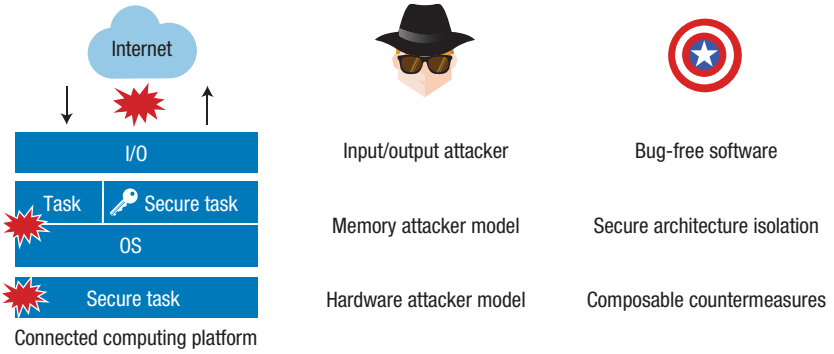

Figure 1. Attacker models in the connected computing platform.

The first assumption is that the hardware architecture of computers might require a deep understanding of isolation and attestation of applications at the hardware level. A rich design space of solutions affects the broad domain of computer architectures, from embedded cores to mainstream processors.[1]

A second assumption is that we might need to revise computing mechanisms itself, developing computing methods that enable the use of computer architectures that might not be fully trusted. Such solutions would integrate cryptographic techniques with computing such that secure data remains protected at all times.[2]

A third assumption is that processor hardware might need to be revised so that it deals with the hardware attacker at the lowest level possible by eliminating harmful observation or manipulation of the physics of computing.[3]

TC will closely follow these exciting developments in secure computer architectures with the latest academic and industry research. Please stay tuned for upcoming issues to keep current on this topic, as well as computing architectures, memory technologies, real-time systems, and much more.

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ELSEWHERE IN THE CS

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Computer Highlights Society Magazines

The IEEE Computer Society's lineup of 13 peer-reviewed technical magazines covers cutting-edge topics ranging from software design and computer graphics to Internet computing and security, from scientific applications and machine intelligence to cloud migration and microchip design. Here are highlights from recent issues.

Computing in Science & Engineering

Glimpses of Space-Time beyond the Singularities Using Supercomputers

A fundamental problem of Einstein's theory of classical general relativity is the existence of singularities such as the big bang. All known laws of physics end at these boundaries of classical space-time. Thanks to recent developments in quantum gravity, supercomputers are now playing an important role in understanding the resolution of big bang and black hole singularities. Using supercomputers, explorations of the very genesis of space and time from quantum geometry are revealing a novel picture of what lies beyond classical singularities and the new physics of the birth of our universe. Learn more in the July/August 2018 issue of *Computing in Science & Engineering*.

IEEE Annals of the History of Computing

Oral History of Dame Stephanie Shirley

Dame Stephanie ("Steve") Shirley is one of Britain's most celebrated IT pioneers, entrepreneurs, and philanthropists. In 1962, she founded a contract programming company exclusively for women, seeing untapped potential in the large numbers of educated women who had left work to raise children at home. Shirley's company grew rapidly and had a successful IPO in 1996. Since retiring, Shirley has spent her time supporting various IT-related causes and, most recently, organizations researching and providing services to those with autism. This interview, which appears in the January–March 2018 issue of *IEEE Annals of the History of Computing*, is based on an oral history conducted by Marie Hicks, professor of history at the University of Wisconsin at Madison, on behalf of the Computer History Museum.

IEEE Cloud Computing

The Business Case for Chaos Engineering

While chaos engineering has gained currency in the site reliability engineering community, service and business owners are often nervous about experimenting in production. Proving the benefits of chaos engineering to these stakeholders before implementing a program can be challenging. This article, which appears in the May/June 2018 issue of *IEEE Cloud Computing*, presents the business case for chaos engineering through qualitative and quantitative tactics, as well as the benefits and tools to convince stakeholders that chaos engineering is necessary and cost-efficient.

IEEE Computer Graphics and Applications

Weather Report: A Site-Specific Artwork Interweaving Human Experiences and Scientific Data Physicalization

Weather Report is a site-specific art installation that entices visitors to examine climate change at human scale, both physically and metaphorically. Weather data is displayed using balloons as physical pixels that can be touched, part of an effort to make objective, scientific data graspable by non-scientists. Visitors contrast the objective weather data with their own weather-related memories to create a subjective weather record from the Twin Cities community. Read more in the July/August 2018 issue of *IEEE Computer Graphics and Applications*.

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IEEE Intelligent Systems

Adaptive Biometric Systems Using Ensembles

With the increased availability of online services, enhanced authentication mechanisms—including biometric systems—are necessary. However, recent studies show that biometric features can change, affecting recognition performance over time. Adaptive biometric systems that can automatically adapt to the biometric reference have been proposed to deal with this problem. Frequently, these systems use query samples classified as genuine to adapt the biometric reference. Despite good results, there are concerns regarding their robustness. This article, which appears in the March/April 2018 issue of *IEEE Intelligent Systems*, investigates using an ensemble of classifiers to increase these systems' robustness. The authors explore questions regarding the application of ensembles to adaptive biometric systems using one-class classification algorithms, and offer a proposal to automatically adapt the meta classifier over time.

IEEE Internet Computing

The Web for Underpowered Mobile Devices: Lessons Learned from Google Glass

This article examines some of the potential challenges associated with enabling a seamless web experience on underpowered mobile devices having display capabilities such as Google Glass from the perspective of web content providers, devices, and networks. Researchers conducted experiments to study the impact of webpage complexity, individual web components, and different application layer protocols while accessing webpages on the performance of the Glass browser. They measured webpage load time, temperature variation, and power consumption and compared them to a smartphone. Read more about their findings in the May/June 2018 issue of *IEEE Internet Computing*.

IEEE micro

Uncovering the Security Implications of Cloud Multi-Tenancy with Bolt

Cloud providers routinely schedule multiple applications per physical host to increase efficiency. The resulting interference on shared resources often leads to performance degradation and, more importantly, security vulnerabilities. Interference can leak important information about an application, ranging from services placement to confidential data such as private keys. As a solution, the authors of this article from the May/June 2018 issue of *IEEE Micro* present Bolt, a practical system that accurately detects the type and characteristics of applications sharing a cloud platform based on the interference an adversary sees on shared resources.

IEEE MultiMedia

Behavior Analysis through Multimodal Sensing for Care of Parkinson's and Alzheimer's Patients

The analysis of multimodal data collected by innovative imaging sensors, Internet of Things devices, and user interactions can provide smart and automatic distant monitoring of Parkinson's and Alzheimer's patients and reveal valuable insights for early detection and prevention of events related to their health. This article, which appears in the January–March 2018 issue of *IEEE MultiMedia*, describes a novel system that involves data capturing and multimodal fusion to extract relevant features, analyze data, and provide useful recommendations. The system gathers signals from diverse sources in health monitoring environments, understands user behavior and context, and triggers proper actions for improving the patient's quality of life.

IEEE Pervasive Computing

Harnessing the Power of Patient-Generated Data

The authors of this article from the April–June 2018 issue of *IEEE Pervasive Computing* report on the PervasiveHealth 2017 workshop, Leveraging Patient-Generated Data (PGD) for Collaborative Decision Making in Healthcare. They discuss characteristics of PGD, followed by scenarios demonstrating the data-sharing practice among patients, clinicians, and caregivers. The authors also highlight current challenges and opportunities, and outline a future research agenda to envision ways to harness the power of PGD.

IEEE Security & Privacy

AI and the Ethics of Automating Consent

Artificial intelligence (AI) systems collect, process, and generate data in ways that further exacerbate many long-documented problems with online consent, most notably issues of providing adequate notice, choice, and withdrawal to users. The unpredictable and even unimaginable use of

data by AI systems is considered a feature, not a bug. Yet this feature creates problems for notifying users as well as assessing when consent might be required based on potential uses, harms, and consequences. This article, which appears in the May/June 2018 issue of *IEEE Security & Privacy*, investigates whether these problems impact morally transformative consent in AI systems. The authors argue that while supplementing consent with further mechanization, digitization, and intelligence might improve take-it-or-leave-it notice and choice-consent regimes, the goal for AI consent should be one of partnership development between parties, built on responsive design and continual consent.

IEEE Software

A Comet Revisited: Lessons Learned from Philae's Landing

The Philae lander, part of the Rosetta program, was the first to land on and explore a comet. This article explores the lessons learned from the Philae team's experiences with problems that occurred in the hardware and software and in mission operations control. Read more about András Balázs' analysis of what went wrong in the July/August 2018 issue of *IEEE Software*.

IT Professional

Digital Health in the Era of Extreme Automation

Digital health has come a long way over the past few years and has become a giant platform that integrates clinical communication, care coordination, virtual visits, mHealth, telehealth, and eHealth. In the era of extreme automation and connectivity, digital health is rapidly changing the healthcare industry by presenting effective solutions to several healthcare challenges, such as interoperability and patient satisfaction. This article, which appears in the May/June 2018 issue of *IT Professional*, explores this vital area for care transformation.

CALL FOR NOMINEES

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See the award details at:
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50 & 25 YEARS AGO

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AUGUST 1968

In its early years, *Computer* was published bimonthly. Stay tuned for more interesting historical highlights in the upcoming September 2018 issue.

AUGUST 1993

www.computer.org/csdl/mags/co/1993/08/index.html

Computer Society Treasurer's Message—1992 Financial Results (p. 8) "Recognizing the need to build up the Computer Society's financial reserves, the Board of Governors in 1992 established demanding surplus targets for 1993 and 1994. ... The result was a welcome improvement in our financial picture: The society ended 1992 with a $515,300 surplus compared to a $490,800 loss the year before." *[Editor's note: This detailed financial statement explains the type of actions that led to financial improvements. It's clearly worth reading to get ideas on what to do regarding today's similar financial problems.]*

Guest Editors' Introduction: Extending Telecommunications Systems—The Feature-Interaction Problem (p. 14) "One day not far in the future, you will be struggling to compose a technical report on your home computer. You set up a conference with several colleagues, who are your coauthors. During the conference, you converse with your colleagues while seeing them on screen. They also see an image of your report on their workstations. You have begun to make some progress on the report when your working session is suddenly suspended and replaced by an emergency call from the school nurse; your daughter has been struck in the abdomen by a hockey stick. While you talk with the nurse, a call from a telemarketing firm is routed to your voicemail system. When you resume the session with your colleagues, you explain the situation and quickly arrange for the remainder of their discussion to be recorded for your later review. You then call your spouse's personal communications number and are routed through in the midst of a sales meeting at a client's business. You relay what has happened and you both agree to meet at the hospital emergency room. This scenario is feasible because each of these new telephone features exists today. However, their appearance in the telephone system as a group of compatible features might take much longer than expected. The problem? Every new feature can change the behavior of pre-existing features or even 'break' them, crashing the system. In the telecommunications industry, we call this the feature-interaction problem. It is a key obstacle to rapidly adding new features to the public network and evolving it to meet user needs. ... " *[Editor's note: Overall, this editorial and the accompanying articles are very focused on telecommunications and ignore events in other complex systems. Also interesting to note is that although the Internet existed in 1993, it wasn't mentioned in any of the examples cited.]*

Feature Interactions and Formal Specifications in Telecommunications (p. 20) "This tutorial is aimed at computing scientists and engineers who are interested in the telecommunications domain. It explains the feature-interaction problem and explores the relationship between feature interactions and formal specifications. The article assumes some acquaintance with commonly known techniques for formal specification. ... I also show how many feature interactions can be eliminated by applying known techniques of formal specification (along with a suitable amount of foresight). But I also tell the other side of the story: feature interactions that current specification techniques cannot handle satisfactorily. I hope that these examples inspire new ways of looking at systems and new techniques for formal specification. ... What is a call? 'Call' might be the most commonly used term in telecommunications, but these days we must be careful not to make unwarranted assumptions about it. For example, no individual party is indispensable to a call. Features such as conference, transfer, and drop let users add and delete parties to an ongoing call, so that the conversation can continue while its membership changes completely. The ultimate in dynamic calls is the chat line, an ongoing public call that

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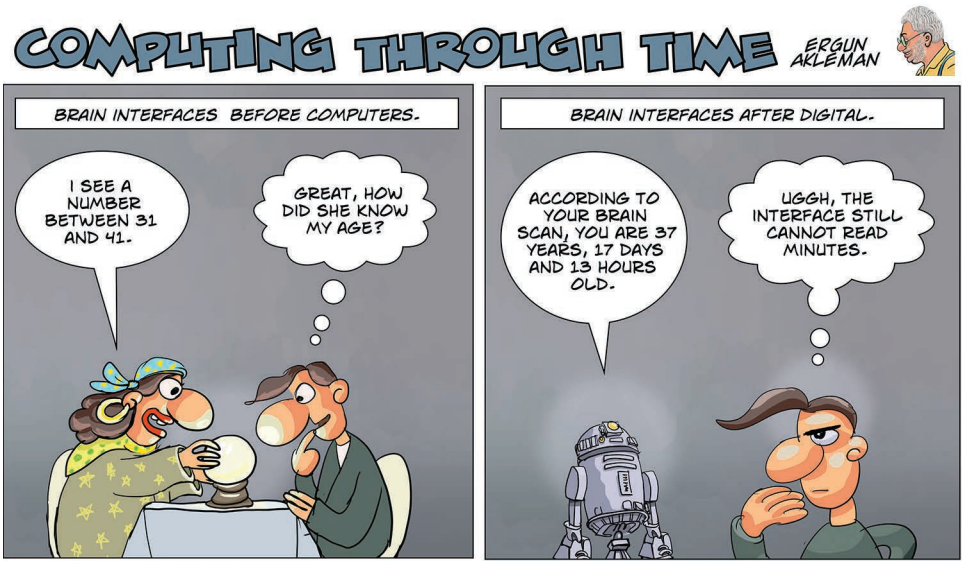
parties can enter and leave at will." *[Editor's note: This tutorial lists many of the features of modern telecommunications but leaves out all aspects of data transfer. Obviously, it was not considered essential before the Internet became widespread. Unfortunately, aside from mentioning finite state automatons, the article did not discuss how feature interaction would be handled.]*



Improving Public Switched Network Security in an Open Environment (p. 32) "Recognizing that the public switched network is increasingly vulnerable to hostile users, the federal government has stepped up efforts to maintain the integrity of telecommunications services. ... A second NSTAC [National Security Telecommunications Advisory Committee]network security report, released in 1992, contained an updated risk assessment confirming that malicious hackers continue to penetrate PSN (public switched network) systems and intrude upon sensitive government interests. Outages experienced by telecommunications providers have also helped to focus the federal government's attention on the need to ensure dependable communications. ... Working with the National Communications System (NCS), the National Institute of Standards and Technology (NIST) has identified some additional concerns: Feature interactions could disrupt a needed service or be targeted for intentional abuse by malicious users. The potential for undesirable feature interactions will increase as more services are added to the network." *[Editor's note: A large amount of work has been done since 1993; however, as the reoccurrence of intrusions and malicious malfunctions has shown, more remains to be done to satisfy reliability, security, and privacy concerns in such systems.]*

Formal Models of Communication Services: A Case Study (p. 37) "Formal methods can play an important role in exploring these new services. The telecommunications and data communications communities have long accepted the need for formally describing protocols, but only recently have they considered formally describing a service by abstracting specifications from a particular protocol that provides that service. Specifying a service at an abstract level meets two important needs: standardization and customization. ... To illustrate the uses of the formal model, I also describe a simple protocol for providing an atomic multicast service. The example is not realistic in that it ignores all sorts of failures, but it is short and does demonstrate the model's features. The protocol provides one service by making use of a lower level, simpler service. In this example, I use a service that reliably passes data from any node to any one neighbor, preserving order between each pair of nodes."

Distributed Artificial Intelligence [DAI] for Runtime Feature-Interaction Resolution (p. 48) "DAI extends distributed processing so that the computers reason about when to interact with other systems and what information to exchange. Interactions are then more flexible to reflect particular, possibly changing, requirements for a specific system and changes in a system's environment, such as the emergence of other systems. ... The DAI literature includes a number of approaches that address the feature-interaction problem. Here I describe four. LODES (Large-Internet-work Observation and Diagnostic Expert System), TEAM-CPS, and Multistage Negotiation primarily address interactions of different administrative domains. An agent encapsulates the network management system in one administrative domain. TEAM-CPS, Multistage Negotiation, and Negotiating Agents address resource contention in cases of limited network support. The Negotiating Agents mechanism also deals with personalized instantiations. ... Constraints of the application domain. The agents' tasks are complicated by additional constraints on the problem-solving process: Telecommunications systems are dynamic; they do not stop during problem solving and they have strict availability and response requirements. Cooperative problem solving in such an environment must therefore be fast and reliable, without consuming too much processing power and communication bandwidth. ... Applying DAI approaches to feature interaction also raises interesting research problems. Systems need evaluation functions to rate generated proposals, possible but not-yet-generated proposals, and constraints. Moreover, different problem-solving processes might interact and interfere with each other."

InterBase: An Execution Environment for Heterogeneous Software Systems (p. 57) "InterBase integrates pre-existing systems over a distributed, autonomous, and heterogeneous environment via a tool-based interface. It supports heterogeneous applications without violating the local autonomy of component systems. ... As the InterBase focal point, the distributed Flex transaction manager (DFTM) interprets and coordinates the reliable execution of global transactions over the entire system. It provides a unified and flexible interface, the IPL language, with which system programmers can specify the data and control flow of a global transaction. The Remote system interfaces (RSIs) are specially designed InterBase agents that are superimposed on individual local systems. RSIs provide a uniform interface that buffers the heterogeneity of local systems, thus relieving the DFTM from dealing with each local system directly." *[Editor's note: This architecture reflects the five-level architecture that has been widely used to deal with the interoperation of heterogeneous distributed database management systems. This article is especially interesting because it covers installed systems and, therefore, discusses all the issues that arise when moving outside of a research/prototype environment.]*

Finalists Shatter Records in 1993 Gordon Bell Prize Competition (p. 73) "The performance reported by the top entry was over eight times that of the previous best, and two entries exceeded 60 billion floating-point operations per second. More significantly, 12 entries achieved sustained rates exceeding 25 percent of the theoretical peak performance of the machines they ran on. Price/performance improved by almost 600 percent to 7.5 Gflops per million dollars." *[Editor's note: Compare this to the performance of the current world leader Summit: 200 Petaflops and about 3 million times as fast at a cost of $200 million, or $1 per Gflop.]*

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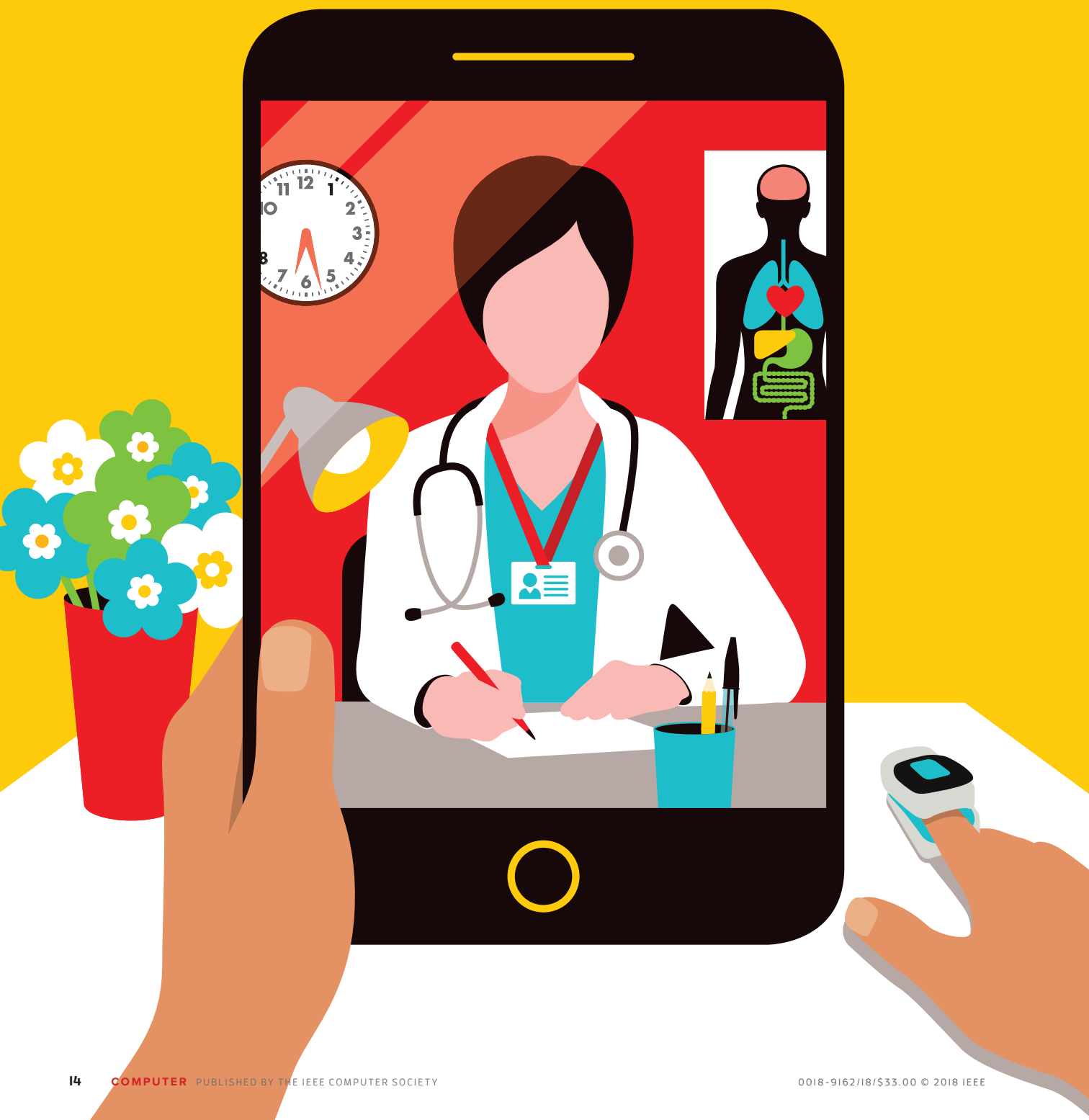

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Towards the Next Generation of Mobile-Driven Healthcare Support Services

Oresti Banos, University of Twente
Chris Nugent, Ulster University

Smartphones are revolutionizing the way people perceive and interact with both physical and cyber worlds. Mobile coaching (m-coaching) is expected to become a crucial contributor to such a revolution by enabling a new way of providing and receiving personalized healthcare.

How important are smartphones in your life? You may have asked this question yourself or have been asked this question by someone you know. The short answer for most people is "very." And the trend seems to grow toward an even greater dependency.

Is this bad?

Well, in general terms, as long as dependency does not translate into addiction, smartphone users will mostly encounter benefits. This positive perception certainly explains the significant adoption of smartphones in recent years,[1] which has increased dramatically, irrespective of gender, age, or social background. As a consequence, smartphones have helped—and they continue to do so—to democratize and accelerate the provision of many services that would otherwise be difficult to obtain. Healthcare is perhaps the most necessary and relevant of such services, and smartphones are helping to pave the way to a new generation of care.

While there are several relevant applications of smartphones in healthcare,[2] such as remote diagnosis, training for workers, or epidemic outbreak tracking, in this issue we particularly focus on the use of smartphones as a potential enabler of a recent emerging scientific area termed e-coaching. As we introduced in an earlier issue,[3] e-coaching exploits the enormous possibilities offered by modern smart systems to persuade people toward a given goal via personalized education and guidance. E-coaches are virtual entities that implement human skills such as observation, questioning, reasoning, or advising to provide tailored and effective assistance to individuals. Smartphones are instrumented by default with a myriad of multimodal sensing, machine learning, and multimedia communication and interaction capabilities that make them particularly suited to embody e-coaching solutions.

Multimodal sensing. The vast majority of smartphones implement a variety of physical sensors such as accelerometers, gyroscopes, or magnetometers that were originally intended to support basic operations such as screen rotation. These sensors are now

used in several commercial applications to estimate the user's activity levels or to track their mobility patterns. Other communication-based sensors such as Bluetooth or Wi-Fi, which are primarily used for interfaces between smartphones and other devices and networks, are now being considered for their ability to detect social cues such as isolation and loneliness.[4] Virtual sensors such as experience sampling methods are also being used for collecting user's self-perceptions to measure, for example, cognitive functioning.[5]

Machine learning. Until recently, mobile healthcare applications were mostly constrained in their functionalities by the limited CPU and memory capabilities of regular mobile devices. With the advent of more powerful smartphones, and APIs that allow developers to harness all the capabilities of the hardware, it is now much more feasible to run sophisticated machine learning algorithms on smartphones. That is the case of modern, computationally demanding strategies such as deep learning, which have shown spectacular results while operating on either servers or powerful workstations, and which are just lately becoming a real option on smartphones too.[6]

Multimedia communication and interaction. There is a clear trend towards mobile health, as smartphones and tablets are gradually becoming the preferred terminals and interface for the interactions between healthcare services providers and end users. Smartphones implement a myriad of communication means, such as messaging, audio, or video, which are of particular interest when it comes to advising users with potential disabilities. More advanced interfaces such as augmented and virtual reality can also be rendered in most smartphones, and as such, they are exciting options for building virtual scenarios and coaches to assist people. Novel concepts involving multiparty e-coaching are also exploring the use of distributed virtual agents over different interfaces to increase adherence and engagement.[7]

M-coaching, as it happens to occur alongside its alter ego, e-coaching, is still in its infancy. The enormous possibilities that m-coaching could bring to our current healthcare system could fairly be extrapolated to other relevant domains such as education, government, or industry. Committing to innovation in m-coaching demands a holistic and multidisciplinary approach, where people from different backgrounds and expertise join efforts to build the next generation of mobile-driven healthcare support services. Do you want to join?

ABOUT THE AUTHORS

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IN THIS ISSUE

This special issue features three articles that address important technical and social aspects of m-coaching systems for healthcare applications.

In "Using eMMA to Manage Medication," Mauro Tschanz, Tim Lucas Dorner, Jürgen Holm, and Kerstin Denecke present a mobile-based electronic medication management assistant to empower patients in handling drug consumption, food interactions and relevance of taking their medication. Their system uses a chatbot, a technology increasingly available in multiple customer support services, to let the patient ask questions relating to their medication. In this manner, users can be coached with respect to their medication, reducing double prescription and medication misuse, and avoiding contraindications and medication errors. Not only does the system have an informative nature, however, it also gathers information on intake compliance via the user-mobile

conversation. Participants found the system easy to use and learn.

In "Social Media–based Conversational Agents for Health Management and Interventions," Haolin Wang, Qingpeng Zhang, Mary Ip, and Joseph Tak Fai Lau also explore the use of mobile-hosted conversational bots, here to manage and facilitate smoking cessation. Through this intervention the authors found out the more conversations a participant becomes involved in, the less likely they would smoke in the same week. The authors also report on the challenges for the wide adoption of dialog systems in reality despite the advances in conversational agents, which can be lowered by switching human experts and agents.

In "Mobile Decision Support and Data Provisioning for Low Back Pain," Simo Hosio, Jaro Karppinen, Niels van Berkel, Jonas Oppenlaender, and Jorge Goncalves describe a mobile application that offers crowd-based decision support for discovering treatments in addition to lifelog harvesting resources to facilitate low back pain research. The authors elaborate on the willingness of people to donate mobile sensor data, which turns out to be fairly related to users' levels of savviness. The authors highlight the importance of including both expert and non-expert knowledge in the tool, in an effort to increase the interest and acceptation of users. The authors also elaborate on the importance of providing relevant incentives to scale up participation.

These three articles provide a unique insight into the groundbreaking work being undertaken in the m-coaching field. The opportunities that m-coaching will bring to healthcare and other domains are yet to be explored, however, now more than ever we are prepared to embrace this amazing challenge.

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Using eMMA to Manage Medication

Mauro Tschanz, Tim Lucas Dorner, Jürgen Holm, and Kerstin Denecke, Bern University of Applied Sciences

The electronic medication management assistant (eMMA) aims to empower patients to manage their medication and ask questions through a conversational user interface. In addition, eMMA supports a consistent flow of medication data among healthcare providers, reducing errors and increasing medication adherence.

Errors frequently occur in the medication process as a result of overdosing, drug interactions, contraindications, or non-adherence (taking an incorrect dose, taking medication at the wrong times, or increasing or decreasing the frequency of doses without interacting with the prescribing physician).[1,2] Reasons for non-adherence often include patients' forgetfulness, inadequate knowledge, or lack of understanding of the consequences of poor compliance. Therefore, patient education is very important. Drug therapies can also be unsuccessful if there is an inconsistent information flow among healthcare providers.

In recent years, eHealth strategies have been developed in European countries such as Germany, Austria, and Switzerland with the goal of making accurate and current medication lists available for patients and their healthcare teams.[3] A federal law on the Electronic Patient Dossier (EPD) went into effect in Switzerland at the beginning of 2017, stating that by 2020 all hospitals (and all nursing homes by 2022) are expected to have an EPD implementation, with the goal of making relevant treatment data accessible to healthcare professionals. An interim solution has been developed, where a healthcare provider generates a paper-based medication list

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that can be digitized by a scannable QR code.[4] Using this QR code, the data can be imported into other information systems to create an updated medication list. A similar interim solution is available in Germany. The application introduced in this article makes use of this technology to support the exchange of medication data among healthcare providers and to allow patients to manage their own medication processes.

There is a growing number of smartphone apps available to help people manage their medication. Studies have shown that electronic mobile devices have the potential of improving medication adherence through reminders sent by short message services (SMS).[5] Delivering self-management support digitally, including support for understanding and managing treatment, has shown improvements in health outcomes and processes of care for patients with chronic conditions.[6] However, most of the currently available apps only provide reminder functions.[7]

In this article, we introduce an electronic medication management assistant (eMMA), which addresses these challenges by providing a mobile application that not only reminds patients to take their medication but also records compliance data, informs patients about the importance of drug adherence, and provides patients' latest medication data to their entire healthcare team.

MATERIAL AND METHODS

Our concept and prototype development were realized in three steps: requirements analysis, concept development, and implementation.

This work was involved in the "Hospitals of the Future Live" project, in which 16 companies and 6 hospitals developed IT solutions for future optimized healthcare processes, taking into account eHealth.[8] For this reason, we were working with a multi-stakeholder principle: requirements were collected from the different actors and integrated into a coherent concept. More specifically, we asked physicians via email and interviews for a description of the current situation and ideas for possible improvements. In addition, we assessed relevant literature to collect requirements and review limitations of existing apps.

eMediplan in Switzerland

An interdisciplinary group of professional associations in Switzerland developed the technical content for eMediplan, a national exchange format for eMedication.[3] It includes the drug name, agent, dosage, image (if available), intake schema including instructions for consumption, reason for intake, and who prescribed the medication. The eMediplan can be printed and given to the patient. A QR code on the printed document allows the data to be imported in a structured format to another information system. In the future, this will also enable health professionals to upload the information from an eMediplan to the EPD. We used the eMediplan QR code to import the latest medication data to eMMA and to export the data to an information system belonging to the treating physician or pharmacy.

Conversational user interfaces

Conversational user interfaces (CUIs) or chatbots allow for text- and language-based interactions between a user and a system.[9] The idea originates from popular text messaging systems such as WhatsApp or Telegram, with the goal of using language-based chatbots to reduce the complexity of user interfaces and simulate a communication similar to human conversations. Chatbots have already been used to help diabetes patients manage their condition.[10] Babylon Health (www.babylonhealth.com), supported by the National Health Service, provides physician advice and guidance using a CUI. Ada (https://ada.com) uses a CUI to help patients find causes of their symptoms. Safedrugbot (www.safeinbreastfeeding.com/safedrugbot-chatbot-medical-assistant) is a chatbot messaging service that offers assistant-like support via the Telegram messaging app to health professionals who need information about using different medications while breastfeeding. However, the application of a CUI as a means of interacting with a system in the healthcare domain is relatively new, so studies on its usefulness are still limited.

Usability test methodology

The usability of the eMMA app was tested with 10 participants (6 men and 4 women) ages 39 to 77, with an average age of 57. The participants were familiar with text messaging applications such as WhatsApp and knew how to use chat systems. All participants used Android, iOS, or Windows-based smartphones on a daily basis. The objective of the usability test was to find out whether the CUI could intuitively be understood and whether the application of this technology is useful in the context of medication management.

The usability questionnaire was based on the DIN EN ISO 9241 standard and presented nine statements that participants were asked to respond to using a scale of one to five, indicating

TABLE 1. Usability test results.

Statement	Disagree completely	Disagree partially	Neither agree nor disagree	Agree partially	Agree completely
It was easy for me to learn how to use the app.			1	6	3
I am able to carry out the tasks without problems.				8	2
The app is easy to use.			1	7	2
The terms used are clear to me.			3	6	1
The process of the application is understandable.				7	3
The app appears clear and comprehensible to me.			1	6	3
Using the app does not require too much mental effort.				4	6
When I use the app the next time, I know immediately how to use it.				2	8
I can find all the information I need.			1	8	1

the degree of agreement with the statement (1 being total disagreement and 5 being total agreement). The results are listed in Table 1. Furthermore, six app-specific, open questions were added to seek possible improvements and other features and to test specific elements of the system.

Even though the number of participants in the study was low, previous studies have shown that 80 percent of usability problems can be found with only five research subjects.[11] Turner et al. and Lewis et al.[11,12] even claim that the most serious usability problems can be revealed with only three subjects. Because eMMA was not used by the participants for their individual medication management for a longer period of time, a study on the effectiveness of the app with respect to medication adherence remains open for the future.

SYSTEM ARCHITECTURE

The main objectives of eMMA are coaching a patient with respect to their medication, reducing double prescriptions and medication misuse, and avoiding contraindications and medication errors.

Architecture

The architecture of eMMA consists of

- a client implemented as a CUI,
- data-collection services in the form of a barcode scanner and a manual data-entry facility,
- a data-storage component implemented as a data connection to MIDATA (www.midata.coop; a not-for-profit cooperative that enables users to securely store, manage, and control access to their personal data) and as local storage, and
- knowledge resources for retrieving medication information (hospINDEX, a Switzerland-wide database for medication, and Clinical Decision Support [CDS] Check, which provides information on contraindications).

Because different drugs are officially approved in different European countries, we used Swiss-specific knowledge resources. However, the application can be easily adapted to other countries. The web-based medication database hospINDEX stores information on specific medications such as images or normalized strings. For more information, please see the technical documentation (www.hcisolutions.ch/de/products/index-products/documentation.php). We also used HCI's CDS Check (www.hcisolutions.ch/de/datenbanken-und-software/documedis/clinical-decision-support-checks.php), which provides information on contraindications. More specifically, it offers validated checks for food interactions, allergies, and intolerances or doping substances. To integrate this into eMMA, we used the Institute for Medical Informatics (i4mi) library (https://github.com/i4mi/hci-hospindex-api).

Data flow

Whenever medication information is required or new information is added, the current data is collected from the platform or the data from MIDATA is updated, respectively. In this way, double prescriptions and possible drug interactions are recognized. After successful login, eMMA checks for current medication information on MIDATA. If an updated eMediplan exists on the platform, the corresponding data is downloaded, transmitted in the format of the HL7 CDA-CH-EMED Community Medication List (Swiss adaptation of the HL7 CDA Medication Treatment Plan Sharing [MTPS]), and stored on the database of the application by applying the same structure as the eMediplan.

eMMA makes a request to hospINDEX to retrieve the name of the

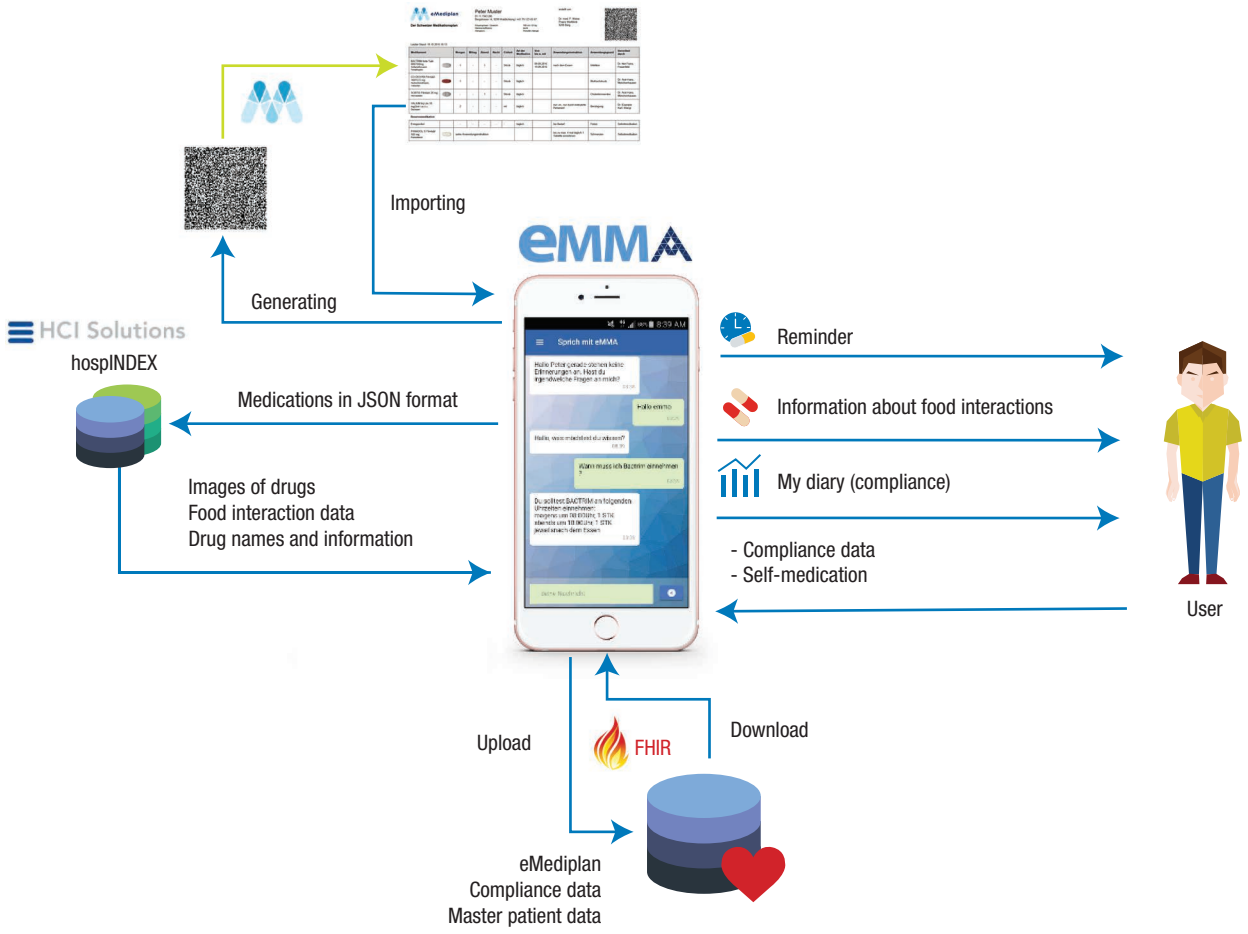

FIGURE 1. The mobile application eMMA (electronic medication management assistant) uses imported data to generate intake reminders, point out food interactions, provide additional information on medication, and record compliance data. FHIR: Fast Healthcare Interoperability Resources.

drug. This allows other drugs to be added that are not yet listed on the eMediplan. For each drug, eMMA collects the corresponding agents using hospINDEX. Furthermore, it checks for food interactions for each active substance by querying CDS Check. The retrieved data is stored locally on the patient's smartphone.

The patient communicates with eMMA over a CUI and can ask specific questions about his or her current medication (such as when to take it or why). As an additional feature, the patient can take a picture of the medication to have better recognition later on. Any interactions with the system, especially conversations regarding drug consumption, are stored in MIDATA. Later, the prescribing doctor can easily access this data when the patient provides the required access rights and allows the doctor to monitor whether the patient is taking his or her medication regularly or whether he or she needs additional guidance.

Functionalities

The eMMA application

- reminds patients about medication intake (see Figure 2),
- lists current medications for personal use,
- points the user to the reasons for taking the medication,
- checks for food interactions,
- provides information to the user upon request,
- collects compliance data on daily drug consumption (see Figure 2 and Figure 3), and
- supports the entire healthcare process.

Data import and export. Drugs can be entered into the app in three ways: manually, by scanning the barcode of a medication, or by scanning the QR code of the eMediplan. To scan the barcode and retrieve the information from hospINDEX, we used the Cordova plugin from PhoneGap. This activates the camera, automatically scans the barcode, and returns the code as a string. The application also generates a QR code that is used to export a stored eMediplan.

Interaction check. Certain foods can largely attenuate or even intensify the effect of a drug. For example, grapefruit has an interaction with the

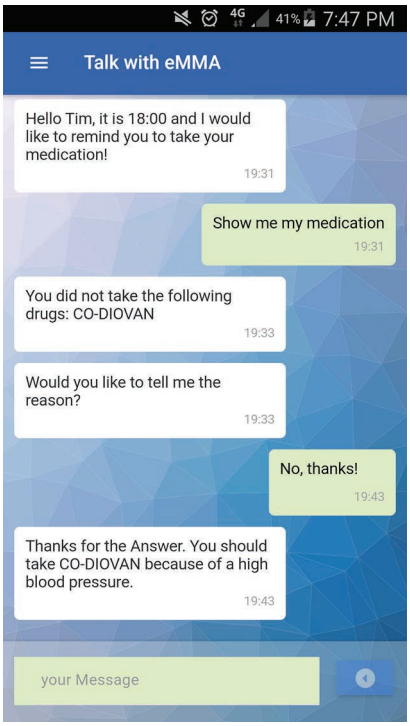

FIGURE 2. eMMA's conversational user interface (CUI). The app is asking a patient why a medication has not been taken.

cholesterol-lowering drug Sortis (atorvastatin). If a patient is not aware of this and eats grapefruit, it can lead to unnecessary side effects. The eMMA application provides information on food interactions with the current medication in a tabular format. This information is retrieved from the CDS Check, which is classified as medical device class I. The underlying database is constantly fed with new information and kept up to date. Each time a new drug is added in eMMA, the medication data is sent via the CDS Check to retrieve the interactions. This requires an Internet connection—otherwise, the nutritional information is not up to date. The drug-interaction check does not aim to provide all possible interactions for a current medication, as this would overwhelm the patient, who often lacks the background knowledge for a correct interpretation and judgment of the actual risks. Instead, eMMA focuses on interactions between food and drugs.

CUI. When eMMA is used by a patient for the first time, he or she is asked to enter their master data (such as name, whether he or she is physically active, and more). The patient is free to choose an additional security pin for the app to protect sensitive data. Besides user name and password, the master data serves as additional information for the interaction checks. For example, the app would like to know if the patient is engaged in high-level sports to alert him or her about possible doping substances.

The query mode is the actual core of the application, and provides information to the patient without navigating through different menus. We expect this to be more intuitive for the elderly. For example, patients can ask questions about how to take a certain drug and why it must be taken.

Upon request, for some specific foods, interactions with the current medication are listed. If only the name of a drug is entered, eMMA asks the user what exactly he or she wants to know about the drug. A drug name followed by one of the query terms "when" or "why" shows the corresponding answer. For example, the drug name followed by the word "why" will show the user why to take the medication.

A challenge for the query mode is, however, that the user must understand that he or she can ask eMMA these questions. For the prototype, we implemented a set of fixed questions and commands to realize the dialog-based user interface, as it was still unclear whether a CUI is useful in this context. Thus, for an initial user study on feasibility, we reduced efforts. In future work, a fully functioning chatbot will be implemented using existing frameworks such as the Artificial Intelligence Markup Language (AIML).

The CUI is used to remind a patient to take his or her medication. As shown in the screenshot in Figure 2, the system asks for compliance data in a non-obtrusive manner. When data is entered in this dialogue, it can be reviewed in the medication diary.

There are five different answer types in the CUI. Depending on the question, the corresponding type is chosen: two buttons, single button, text field, password field, and number field. The buttons are for the user to enter predefined answers. This is the case, for example, for master data collection and reminders. Through text boxes, the user can enter detailed information or ask questions.

Medication diary. The medication diary summarizes the current medication and the patient's adherence (see Figure 3). The patient's compliance is displayed in a bar chart, which provides a quick overview of how often a drug been taken. The compliance diary in Figure 3 shows that the patient did not take half of his prescribed medication on average. For some self-medications like Essigwickel (a fever reducer) and Panadol (a pain reliever), this might not cause serious problems. However, a cholesterol-lowering drug such as Sortis must be taken regularly.

For the bar chart, the individual month and the entire overview can be displayed, making it possible for the patient to show the doctor his or her medication adherence in the last

month. In addition to the statistical evaluation, a table indicates the reason for non-adherence. For example, if the patient wrote that he dislikes the taste of the pills, his doctor could replace that medicine with another one.

USABILITY TEST RESULTS

For all statements listed in the usability questionnaire, the majority of test participants agreed and selected a value of 4 or 5 (for results, see Table 1), meaning they were satisfied with the application to a large extent. Only three participants selected "Neither agree nor disagree" regarding the terms used in the app and whether they were understandable, bringing us to conclude that there are still improvements to be made with respect to the terminology.

The following positive statements were noted:

- The design of the app is appealing.
- I like that I don't have to write a lot.
- The process is clear because I know when eMMA is writing something.
- I'm glad I do not have to navigate with the chat.
- Almost no incomprehensible words.
- Short, concise sentences.
- Storing on MIDATA is easy.

The following criticisms were made:

- I do not know what I can ask in question mode.
- It would be nice if the answer buttons were animated.
- I want to open the scanner for self-medication through chat messages.
- I would like to take pictures of my medication without barcode scanning.
- I cannot change what the app calls me.

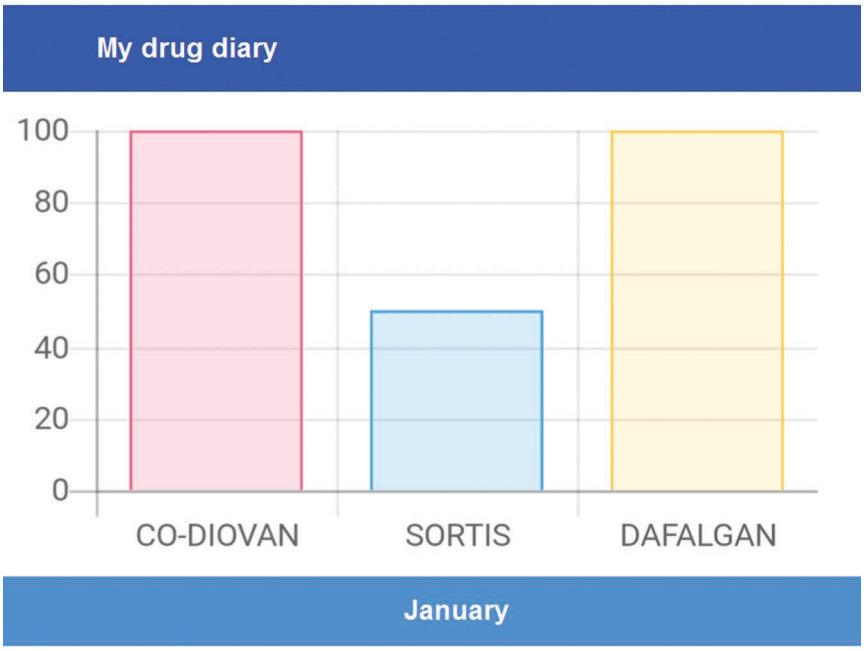

FIGURE 3. Visualization of the compliance per drug. The numbers represent the percentage of how often the drug was taken as instructed.

The usability test shows that participants were able to understand the function of the CUI within minutes and could navigate through the app without large effort.

COMPARISON TO OTHER APPS

A review paper by Ahmed et al.[13] provides a comparison of 420 English-language medication adherence apps. The authors distinguished three categories of adherence strategies used in these apps: reminder, educational, and behavioral. Following this taxonomy, eMMA combines three strategies for adherence: a push notification for the reminder, the CUI as the educational feature, and personal tracking as the behavioral feature. As underrepresented features in existing apps, the authors listed barcode scanning and integration of a drug database, as well as educational strategies. Nearly all existing apps require the patient to manually enter his or her prescription data, which carries the risk of entering incorrect data. Thus, eMMA differs from existing medication adherence apps by providing educational features and barcode scanning for simplifying the data entry.

To the best of our knowledge, there is no mobile application available that uses a CUI and supports medication management and data transfer among healthcare providers. In their review of medication adherence apps, Dayer

et al.[2] concluded that identifying the reasons for non-adherence would be useful in effectively deploying app reminders. Through eMMA's CUI, a patient can be motivated to take his or her medication and compliance data can be collected. This allows us to get one step closer to patient empowerment: motivating a patient to take their medication and presenting possible drug interactions provides the patient with more responsibilities. The responsibility for the complete drug therapy will still be with the doctor or pharmacist, however, because the patient most likely cannot fully understand all the possible interactions.

Studies show that patients generally become more aware of their therapy and behavior when the behavior is recorded. In the case of an HIV study,[14] it was shown that patients who regularly fill out a questionnaire regarding their illness generally want to think more about their illness and behavior. After extending eMMA's communication capabilities, a study will be performed to analyze whether it facilitates medication adherence.

LIMITATIONS

The eMMA application is limited in two relevant ways. First, the app must be connected to the Internet during use—otherwise, no images are displayed and synchronization with MIDATA or an EPD is impossible. Second, the app's data exchange relies on the acceptance of the eMediplan by the attending doctor. The future acceptance of the eMediplan in Switzerland is still unknown. Instead of collecting current medication data using the eMediplan, the data could be directly stored and updated on a future eHealth platform by the healthcare provider. eMMA could then directly retrieve the data from the platform and the QR code would no longer be necessary. Even without using an eMediplan, the app can still provide relevant information, coach the patient regarding medication consumption, and provide statistics on compliance. However, using the eMediplan is ideal because otherwise every medication's barcode must be scanned.

In addition, the CUI works with fixed keywords and is quite restricted in the amount of interactions. We implemented the query mode in such a way that only keywords can be used for the query—for example, the patient would type "how Sortis" instead of "how do I take Sortis." However, this impacts the feeling of having a proper conversation, so a more flexible chatbot is necessary. Medical terminology needs to be detected automatically in user responses for the app to react appropriately and then store the relevant information of the conversation in a normalized manner. The study performed for this article convinced us to invest in the development of a conversational agent that is capable of reacting in a personalized manner to patients' questions and concerns.

eMMA supports individuals' medication management by making relevant medication data and related information available and by storing compliance data, and it provides a prototype implementation of a CUI with a use case in the healthcare domain. A usability analysis demonstrated that users are interested in interacting with eMMA in this manner. In future work, a conversational agent using deep learning or rule-based mechanisms will be integrated. Once the chatbot is more comprehensive and semantically enriched, future studies with eMMA are necessary to study whether medication adherence can be improved using the application. Additional conversational modules could be added to eMMA for realizing more comprehensive patient support—for example, one module could support diabetes management, another module could support general care, and another could provide medical records.

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Social Media–based Conversational Agents for Health Management and Interventions

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Conversational agents could provide timely and cost-effective social support to promote behavioral changes and improve healthcare outcomes. The authors evaluated the performance of their social media–based conversational agent in a smoking cessation program. Results showed that the presence of a conversational agent effectively increased participant engagement and enhanced their smoking cessation outcomes.

Unhealthy behaviors, such as smoking, alcohol abuse, and physical inactivity, are the leading risk factors for many health problems worldwide. Promoting behavioral changes is crucial to improving quality of life and healthcare outcomes. However, cost-effective methods must be developed to promote physical and mental well-being. Computer-aided systems can potentially fill this gap, given their accessibility and popularity. Conversational agents (for example, chatbots) can create a social environment in online support groups and, thus, have been successfully used in healthcare, business, education, and entertainment.[1] Social media plays an increasingly important role in providing health-related information and social support to users.[2]

The development of conversational agents for healthcare applications has attracted considerable interest in recent years. A conversational agent can be an effective partner, rather than a tool, by providing information to increase users' intention to interact with the system and accept the health-related recommendations. For example, Timothy Bickmore and his colleagues designed an

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automated health counselor agent to promote physical activities and fruit and vegetable consumption.[3] Their experiments demonstrated that automated health intervention software can be effective in changing health behaviors. An increasing number of users have gained access to information through smart devices with the development of mobile computing. David Griol and Zoraida Callejas developed a context-aware multimodal conversational agent for mobile phones and successfully used this system to help Alzheimer's patients preserve their cognitive abilities and enhance their relationships with the environment.[4] Despite the rich literature on developing conversational agents for specific diseases, it is challenging to develop a general platform that can be implemented for multiple diseases.

The benefits of group interactions for intervening in health problems are well-recognized. Support groups are valuable for providing informational and emotional support to those with particular health conditions. Extensive evidence shows that group-based intervention can lead to health improvements for participants.[5] Online and mobile-based social supports have been utilized as novel and effective approaches to decreasing depression and enhancing quality of life, leveraging the advances in mobile computing and the Internet.[6] Owing to the anonymous nature of the Internet, it is easier for Web users to express themselves and reveal their health conditions in online communities. Online social communities can complement other methods to distribute health-related information and increase motivation for behavioral changes.

Smoking is a leading cause of various health problems. Smoking cessation can reduce the risk of developing smoking-related diseases and increase life expectancy.[7] Existing studies have shown that online interventions are valuable for smoking cessation considering their broad spectrum. For example, several popular and successful online social networks focus on smoking cessation.[8] Interactive online interventions improve the cessation rate by providing personalized information in a "face-to-face" manner.[9] In addition, social networks significantly influence the initiation and cessation of smoking.[10]

EXISTING STUDIES HAVE SHOWN THAT ONLINE INTERVENTIONS ARE VALUABLE FOR SMOKING CESSATION CONSIDERING THEIR BROAD SPECTRUM.

Understanding of the influence of conversational agents on people's health-related behaviors remains limited, despite a growing number of related studies. In the present research, we developed a mobile-based health intervention system that integrates a conversational agent with an instant messaging (IM) platform to manage and facilitate timely health interventions. We demonstrated the effectiveness of the developed system by applying it to a real-world smoking cessation practice.

The contributions of this article are threefold. First, we propose a general framework to integrate a conversational agent with the WeChat platform (www.wechat.com/en), which is a popular mobile-based social media platform that primarily focuses on IM to provide effective social support for online groups. Compared with developing a new application, integrating the system with a general-purpose mobile-based platform could facilitate the adoption of a conversational agent.

Second, we present a conversational agent designed to communicate with users in a multiparticipant setting[11] to enhance its influence on the health behavior of the community. Despite the advances in conversational agents, the inherent complexity of simulating human conversations remains a challenge to the real-world wide adoption of dialogue systems. To address this problem, the proposed conversational agent shares the same account as the administrator to enable seamless switching between humans and agents, providing improved flexibility and practicability.

Third, we evaluate the performance of the system by looking at the temporal behavior of users in smoking cessation groups and the quit rate of participating smokers. Our research demonstrates that conversational agents can effectively increase the frequency of mutual conversations and enhance the outcome of smoking cessation programs.

METHODS

Compared to forum-based online health communities, IM-focused social media

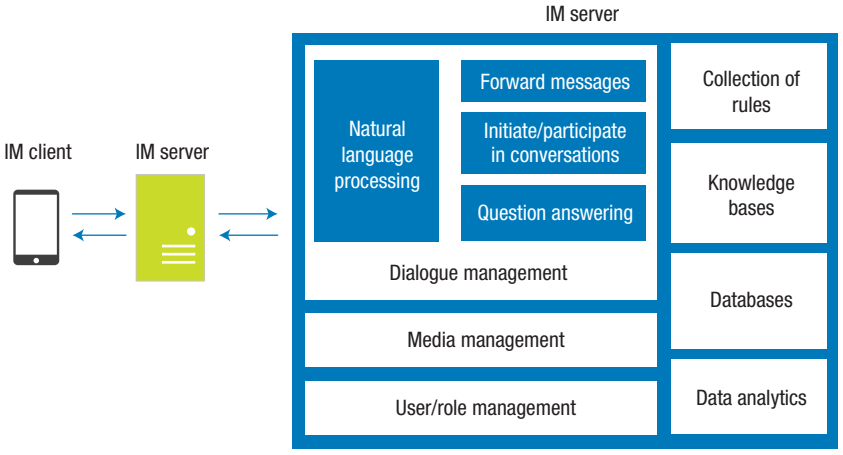

FIGURE 1. Architecture and basic workflow of a proposed conversational agent for a smoking cessation program.

could further enhance the social integration and interactions of users. In this research, we adopted the WeChat platform to implement the conversational agent system because of this platform's wide popularity and user-friendly interface for extensions. The architecture and basic workflow are illustrated in Figure 1. The conversational agent was integrated with WeChat through its public Web API services. Administrators can create groups within WeChat and invite participants to join. Participant messages are sent to WeChat's IM server and to a separately constructed conversational agent server when these participants communicate with one another in the groups. The conversational agent processes a message and sends it back to the IM server. Finally, this message is publicized in the group; hence all users can view it through their WeChat client. The entire process spans less than a second, with no sluggish feel for users.

The proposed conversational agent system contains three main modules for dialogue, media, and user management. Currently, this conversational agent is a rule-based system driven by a collection of rules preprogrammed by domain experts. Advanced artificial intelligence–based systems can be easily integrated by extending new modules through an application interface.

Dialogue management module

Context-aware dialogue management plays a central role in the conversational agent. The conversational agent system is generally context-aware. To be more specific, the dialogue system records the data of all conversations in the group, so that the system can extract context information such as the basic statistics of a participant's activities, prior interactions between a participant and the agent, and so on. The natural language processing module analyzes the text content of each message. Then, the system directly forwards the message back to the system or triggers certain actions on the basis of the preprogrammed rules. For example, when a user sends a message containing a specific keyword that requires action, the conversational agent immediately responds with information that corresponds to that keyword.

In addition, this module initiates new conversations on the basis of preprogrammed intervention plans. Another important function of this module is the capability to privately talk with an individual user. The system utilizes individual conversations to send reminders to nonactive users, and to distribute questionnaires to track each user's progress. The system maintains an individual record of each user's dialogues to enable personalized information services.

User management module

This module is designed to manage individual users and groups. We organized multiple smoking cessation groups to balance the activeness of groups and social integration of users. The system records detailed information about user conversations at group and individual levels.

Multimedia management module

The conversational agent supports image uploading, sending, and updating through this module to allow image and video exchange in the groups.

These three main modules are supported by three additional modules that provide rules, knowledge, and analytics tools, as well as databases.

Collection of rules

The basic elements of rules include the conditions and actions for different scenarios. For example, the proposed system could respond to specific messages by detecting keywords and participate in conversations on the basis of preprogrammed conditions. The

proposed system could also be used to automatically answer frequently asked questions. For example, a user might ask, "What is the harm of smoking?," as depicted in Figure 3(d). The system identifies the keywords "harm of" and "smoking" and automatically responds with a preprogrammed message: "Smoking may affect the functions of your lungs and causes multiple diseases, including pneumonia, emphysema, and lung cancer. For further details, please refer to https://betobaccofree.hhs.gov/." In our experiment, the conversational agent also sent smoking cessation tips when it detected messages that expressed difficulties in smoking cessation efforts.

Knowledge base module

To improve the understanding of the conversations and utilize domain knowledge, the system uses a knowledge base module to incorporate domain-specific knowledge bases from a semantic web, literature from online libraries, and manually created knowledge. This key module enhances the system with knowledge from other resources. In our pilot study, we extended the system with a medical information retrieval system that we developed using a PubMed dataset.[12] The use of this extension is rare, because the participants have no background in understanding retrieved medical papers. We will design a more user-friendly version of this function in the future.

The conversational agent is triggered by a preset schedule or specific keywords. To better simulate human behavior, we use a set of expressions for the same question to avoid repeating the same messages multiple times. We also randomly delay the responses from the conversational agent. In addition, the schedule for the conversational agent to initiate conversations in groups is based on a certain period (such as "8:00 P.M. ± 10 min") rather than a fixed time. The agent randomly selects a time point within the period to post messages in the groups.

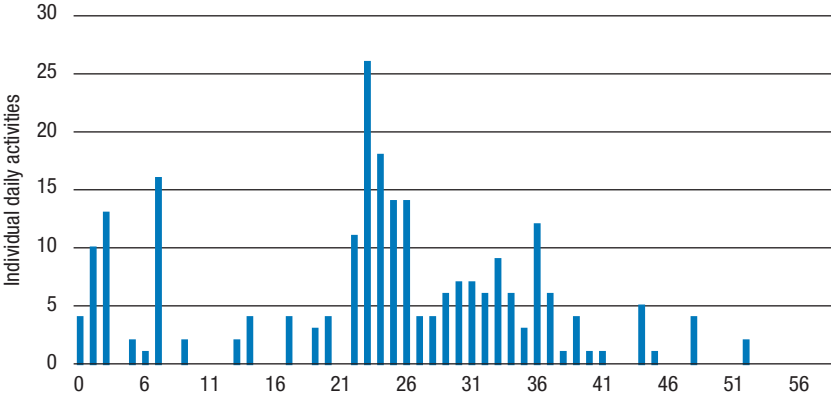

FIGURE 2. Sample of individual daily activities (number of messages) in the support group over two months.

Data analytics module

The data analytics module performs statistical analysis at the user and group levels in real time to monitor the behavior and progress of individual users and groups. This module also automatically creates status reports at the two levels. The conversational agent privately sends a reminder to individuals who have not actively engaged in group conversations for a certain time, such as two weeks. Figure 2 depicts an example of the daily activity of a user group during our two-month experiment, which will be introduced in detail.

EXPERIMENTS

We applied the proposed system to a smoking cessation practice in Hong Kong. Initially, we recruited 401 participants who met the following criteria:

- was a Chinese resident aged 18 or older,
- had smoked in the past seven days,
- had a smartphone and a WeChat account, and
- had not been involved in any smoking cessation program during the past 6 months.

The intervention group consisted of 205 participants (121 males and 84 females), and the control group consisted of 196 participants (118 males and 78 females). The average age of the intervention group and control group was 32.8 and 33.1, respectively. The professions of participants were various, including education, construction, trade, finance, and services. More than one-third (34.7 percent) of participants had received an associate's or bachelor's degree or above. The rest did not have a college education. The participants were assigned evenly to 12 WeChat groups. Some participants

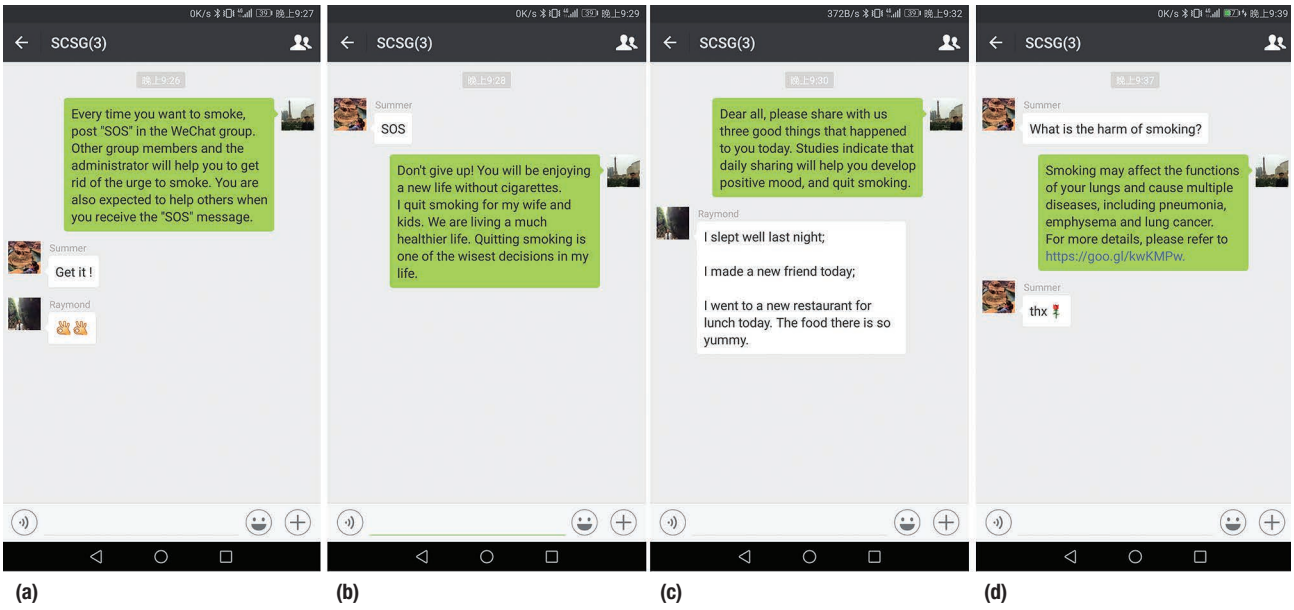

FIGURE 3. Screenshots of WeChat conversations in the Smoking Cessation Support Group (translated from Chinese). (a) Announcement sent by the conversational agent to inform members about the system rules. (b) Response triggered by detection of the keyword "SOS." The response is randomly selected from a set of predefined information. (c) Sharing message triggered by the timer and how a participant responded by sharing three favorable effects with other group members. (d) The QA function of the system.

quit the smoking cessation program at different stages of the experiment. Eventually, 134 participants completed the intervention program. The WeChat groups were formed to help them quit smoking. Each group was set to be active for two months, and then dismissed. We collected 3,808 messages during the two-month period. Of the 196 participants in the control group, 153 completed the program. They only received smoking cessation information and tips without social support or interactions with other participants.

The conversational agent in the group managed the participants' conversations and progress by sending automatic reminders and engaging in conversations. Specifically, the conversational agent sent four types of messages: announcements, sharing, reminders, and responses. Announcements were broadcasted messages to notify group members of information, such as the general purpose and rules of the group and activities. Sharing messages were messages posted by the conversational agent to share predefined favorable effects "experienced" by the agent and valuable health information related to smoking. Reminders were used to remind the group members to share favorable effects they experienced and to maintain an acceptable progress of smoking cessation (encouragement). Responses refer to the information posted by the agent in response to certain keywords (for example, "SOS").

Figure 3 presents screenshots of the prototype system to illustrate the different types of messages. Owing to privacy concerns, we only present hypothetical examples for the testing group of three members. The group name can be customized by participants. Here, we use Smoking Cessation Support Group (SCSG) as an example. Figure 3(a) exhibits an announcement sent by the conversational agent to inform members about the system rules. Figure 3(b) presents a response triggered by detection of the keyword "SOS." The response is randomly selected from a set of predefined information. Figure 3(c) displays a sharing message triggered by the timer and how a participant responded by sharing three favorable effects with other group members. Figure 3(d) illustrates an example of the system's QA function. To facilitate social interactions, the conversational agent does not set

restrictive rules for conversations. A human administrator is also involved in conversations, and can instruct and guide participants in interventions when needed.

We analyzed the temporal patterns of the participants' conversations to evaluate the influence of the conversational agent on the participants' behaviors in the group. The average number of messages per day for each group was 5.24 when the conversational agent was not activated. This number increased by 61 percent (average 8.45 messages) when the conversational agent was activated. This finding indicates that participant activeness is relatively low, and that the existence of a conversational agent improves activeness in general. For consistency, we excluded the messages sent by administrators through the conversational agent.

We defined "active conversation" as a group of messages in which the time interval between any two consecutive messages was less than four hours. In Table 1, the conversational agent was actively involved in more than 57 percent of all active conversations. A detailed observation of the recorded message revealed that more than half of the active conversations were initiated by the conversational agent. This finding demonstrates that the conversational agent plays an important role in maintaining the groups' activeness. We calculated the average number of messages of each active conversation and determined that participants more enthusiastically interacted with one another (average 5.45 versus 3.89 messages) when the conversational agent was involved.

Table 2 summarizes the results of conversations initiated using the four types of messages. We found that the response messages facilitated conversations among group members, with a higher average number of messages in each active conversation. This finding indicates that content-specific interactions (response messages) are more effective than scheduled plans in stimulating user activities (reminder, announcement, and sharing).

TABLE 1. Overview of the 12 support groups' active conversations, by involvement of conversational agent.

Conversational agent	No. of active conversations	No. of messages	Average no. of messages
Involved	455	2,480	5.45
Excluded	341	1,328	3.89

TABLE 2. Conversations initiated, by type of conversational agent message.

Message type	No. of conversations	No. of messages	Average no. of messages
Reminder	227	1,100	5.19
Announcement	49	292	7.30
Sharing	162	787	4.86
Response	17	301	17.71

The temporal behavior of user interactions can be characterized by interevent time distributions. Figure 4 depicts the interevent time distributions of messages in the conversations of each group. We found that the curve was higher with conversational agents than without, thereby indicating that the members are enthusiastically engaged in the conversations and rapidly responded to others' messages when the conversational agents are involved. This result demonstrates the effectiveness of the conversational agent in promoting the intention of group members to communicate.

The conversational agent invited each participant to fill out a private questionnaire regarding his or her smoking cessation progress every week. Of the 134 participants, 105 (78.4 percent) completed these questionnaire sessions. In total, these 105 participants filled in the questionnaire 420 times. Among these returned questionnaires, 38.3 percent reported that the participants had not smoked in the past week, while 69.4 percent reported that the frequency of smoking had been reduced during the past week.

A closer look at the participants' conversations reveals that their social behaviors within the WeChat group were associated with their smoking cessation progress. For instance, a

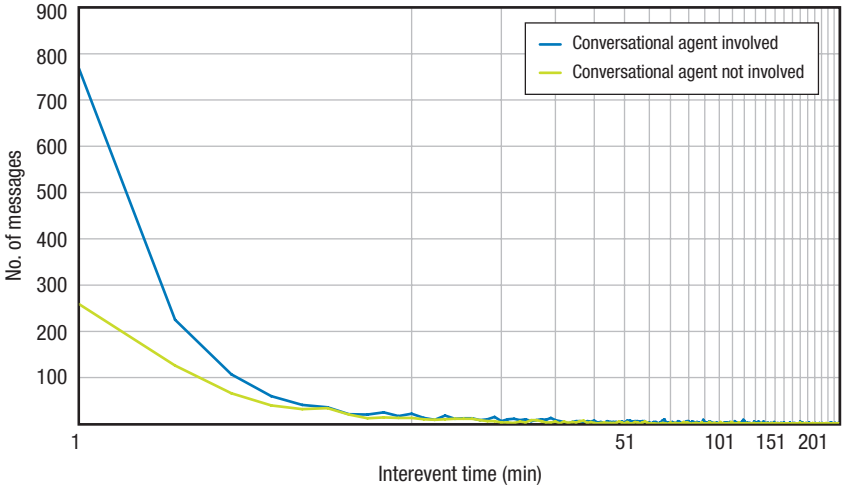

FIGURE 4. Interevent time interval distributions of user interactions.

male participant posted three "SOS" messages in the group to request help on 28 May, 4 June, and 16 June (all 2016), respectively. This participant received multiple responses from the conversational agent and other group members. Examining the questionnaires submitted by this participant for the three weeks corresponding to those three specific days, we found that his smoking frequency was indeed reduced.

We further performed statistical analysis to characterize the relationship between participants' online behaviors in the WeChat groups and their smoking cessation progress. The Pearson correlation coefficient for whether participants smoked in the past week and the number of WeChat conversations they joined in during the past three weeks was positive (0.11). We used the Student's *t*-test to determine the difference between the number of conversations involved in by participants who had not smoked in the past week and those who had smoked in the past week. It turned out that the participants who had not smoked in the past week were involved in a significantly higher number of conversations than participants who had smoked (p = 0.02). This indicates that involvement in conversations within the WeChat group is associated with participants' smoking activities. In particular, the more conversations a participant has, the less likely he or she is to smoke that week.

In addition to the weekly questionnaire, the smoking cessation results were verified six months after the intervention program finished. Finally, participants who reported that they had succeeded in quitting smoking were invited to do a test onsite. Among them, 27 were from the intervention group and 19 were from the control group. The quit rate of participants in the intervention group (20.1 percent) was 62.1 percent higher (p = 0.03, *t*-test) than that of participants in the control group (12.4 percent). On average, within the intervention group, a participant who passed the quit test posted 22.8 WeChat posts, which is 2.5 times the value (9.1) of a participant who failed the quit test. It is worth noting that we do not know the actual status of those who reported themselves to have failed in quitting smoking.

To summarize, the frequency of smoking was lower if a participant gets involved in many conversations within the WeChat group. The participants in WeChat groups (intervention group) had a much higher quit rate than the participants in the control group. The more messages a participant posted in the WeChat group, the more likely he or she was to have succeeded in quitting smoking by the end of the program. To protect the privacy of participants, details of the randomized controlled trial were excluded from this article but are available upon request.

Our research demonstrates the feasibility of a proposed system to integrate conversational agents with an IM platform to support preprogrammed information dissemination, health management, and timely health-related decision support. The proposed system presents a cost-effective approach to promoting behavioral health interventions through smartphones and social media. Our study of user interactions shows that conversational agents are effective in triggering interactions for online groups for domain-specific tasks, such as smoking cessation, thereby providing enhanced social support for a behavioral change that might improve healthcare outcomes.

In future research, we will investigate data-driven approaches to provide additional intelligent and personalized services for individuals by incorporating advanced natural language processing techniques and knowledge

bases, in addition to developing a social media–based conversational agent. In particular, we aim to explore the feasibility of integrating activity monitoring data (such as heart rate, geographic information, and blood pressure) with the text data of conversations. The activity monitoring data can be retrieved through smart wearable devices such as smart watches and fitness bands. On the basis of the data collected from real-world experiments and controlled clinical trials, we will also explore the roles of people in online social support groups and analyze the connections between online activities and offline behavioral changes.

ACKNOWLEDGMENTS

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Mobile Decision Support and Data Provisioning for Low Back Pain

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The authors present Back Pain Buddy, a mobile application offering decision support and coaching for people with low back pain (LBP). The application takes advantage of smartphones' powerful capabilities and provides a crowd-sourced decision support system for discovering treatments and a mobile sensing solution for collecting data about users' activities that are crucial in LBP research.

Low Back Pain (LBP) is the leading cause of activity limitations and missed work throughout much of the world. LBP is a complex issue, and several factors contribute to the condition. LBP has no silver bullet solution, and its global economic ramifications and negative impact on the quality of countless lives, communities, and families is massive.[1] In 1990, LBP ranked as the sixth most burdensome condition in the US contributing to poor health; and two decades later, it causes more disability globally than any other medical condition.[2]

The rise of personal and affordable health trackers has enabled studying, tracking, and even proactively improving several types of health issues. In particular, the so called "medicalized smartphone"[3] is revolutionizing several aspects of medicine. Surprisingly, and despite its massive global burden, LBP is one of the few major medical research areas where not much work has been

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conducted with smartphones. Thus, exploring their potential role in LBP yields a fascinating research avenue.

Our work is highly exploratory in nature, and our overarching aim is to build toward using people's personal smartphones to address two issues specific to the LBP research field. First, the lack of clear therapeutic consensus—despite the condition being extensively documented—results in a plethora of recommended treatments, advocated by various clinicians, practitioners, and commercial operators.[4] The absence of agreement makes it difficult for patients with LBP to select a treatment, especially if they lack access to healthcare (for example, due to a lower socioeconomic status[1]) or turn to the Internet seeking help (for a majority of patients[5]). And second, patients lack sufficient knowledge of LBP-relevant contextual information and lifestyle factors (such as activity levels, physical environment, ambient noise, and subjective experience of LBP).[2]

To address these issues, we present *Back Pain Buddy*, which is a mobile application that provides crowdsourced and trustworthy decision support to address the first issue, and incorporates a powerful mobile sensing solution to address the second issue. Back Pain Buddy is being developed as a partnership among the University of Oulu in Finland, the University of Melbourne in Australia, the Finnish Institute of Occupational Health, and Oulu University Hospital. It is the end user's entry point to a larger scheme to start collecting—for the first time—LBP-relevant contextual information using people's mobile devices in large-scale, longitudinal cohort studies. As an academic venture, we aim for openness of data and free use of the developed technologies. This is crucial, as for-profit corporations are increasingly dominating the personal user data market and pose a direct threat to science and equality (see for example the *Nature News* opinion piece that was published in 2016).[6] Indeed, we predicate our work on legacy and establishing a foundation for future value creation instead of immediately seeking answers to sharply formulated research questions.

The results from our user studies show that the decision support system provides value to its users and that potential Back Pain Buddy end users also thought the mobile sensing solution was feasible. However, users have reservations regarding privacy, ethics, and harmful commercial use of the data, which all need addressing before we can proceed to larger international trials.

LBP IS ONE OF THE FEW MAJOR MEDICAL RESEARCH AREAS WHERE NOT MUCH WORK HAS BEEN CONDUCTED WITH SMARTPHONES.

BACK PAIN BUDDY APPLICATION

The application consists of two components: decision support and mobile sensing. The first prototype of the application contained only the sensing component. We quickly learned, however, that it was challenging to recruit participants to a study where they would not receive any immediate value with the application but instead were "just" donating data. Our best efforts with a collaborating medical organization (Oulu University Hospital) resulted in just a handful of LBP patients installing the application. This was not a sustainable long-term approach toward our goals (outlined in Figure 1).

Nevertheless, this pre-study was encouraging because participants completed self-reports about their LBP condition for several weeks, and we also collected sensor data. However, we need to offer better incentives to scale up participation. To this end, we decided to include the decision support system as an added feature that provides immediate value for end users, so that we could then ask them to donate their contextual data.

CROWDSOURCED DECISION SUPPORT TO DISCOVER LBP TREATMENTS

Crowdsourcing decision support via digital applications is a relatively young but inherently powerful concept: generally, people trust other people who have experienced the issue at hand. Consider the influential nature of customer reviews on Amazon, for example. The same principle helps to offer decision support for any arbitrary multi-answer question, as we have explored in previous work.[7] The decision support system we developed uses crowdsourcing to first break down a question into

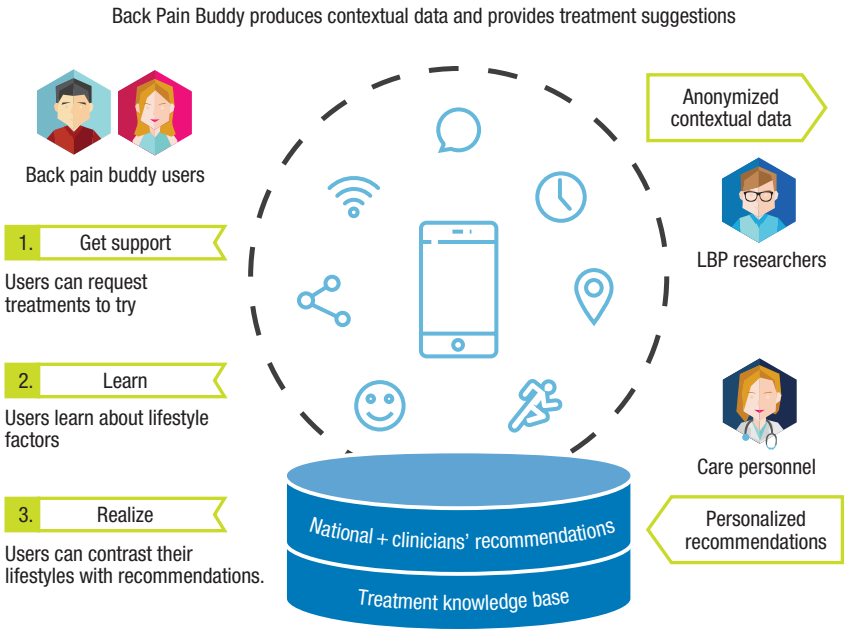

FIGURE 1. Conceptual diagram of our data exploitation plans for the Back Pain Buddy, which collects contextual data and provides treatment suggestions. Users get decision support in the form of ideal back pain treatments. They can also contrast their lifestyle characteristics to clinicians' and government recommendations. Researchers, on the other hand, benefit from collecting contextual information data about the lives of people with LBP.

sets of candidate answers and possible criteria that can be used to assess the answers. Then, the crowd-users assess every answer in light of every criterion, using a "goodness" scale of 1–100. The collected knowledge base encapsulates the wisdom of the crowd that can be used to compute a list of answers that best match the user's ideal solution to the question. Our previous work provides more information on the concept and examples of different computational means to obtain knowledge base decision support.[7]

LBP presents an excellent example of a multi-answer problem that is suitable for use with our decision support concept. Here, we are interested in assisting users to find solutions to the question: *What is a good way to treat low back pain*? To this end, we redesigned the system introduced in our previous work[7] into a mobile-first back-pain–themed decision support component, embeddable in a mobile application. We upgraded the back end to support multiple knowledge sources (crowds), to let end users choose if they want decision support from LBP experts (doctors, physiotherapists), other non-experts (non-experts), or a combination of the two.

The decision support interface is simple and only asks the user to define her ideal back pain treatment using any or all of the criteria available in the system. To achieve this through the app, the user defines ideal criteria for a treatment using slider input elements (Figure 2b). The interface also contains radio buttons to choose the source of the retrieved treatments (experts, non-experts, combination). After setting the ideal criteria in the app, the decision support system fetches the best-matching LBP treatments from the underlying knowledge base (Figure 2c).

Mobile Sensing Component

Smartphones have emerged as powerful research tools for studying human behavior and conditions, thanks to their ubiquity and increasing sensing capabilities. Mobile sensing has risen as a research domain that refers to acquiring and understanding data captured using the array or onboard sensors. Due to a fragmented device (and even OS) base, this is far from trivial, however, and several mobile sensing platforms have been built to ease the data harvesting and aggregation processes.

Especially in the context of LBP, accurate contextual information for patients and potential patients is a key challenge to tackle.[8] Back Pain Buddy is designed to fill this gap. To do this, we make use of the AWARE mobile sensing platform,[9] which is open source, secure, and extensible. This platform enables us to collect and provide access to data on our own servers. It supports plugins, thus we can implement and run any custom native code—a crucial feature for our custom data collection needs. This also allows the user to be in full control of what data is collected, as can be seen in Figure 2e. Using AWARE as a library in Back Pain Buddy, we can capture the following 10 types of contextual data,

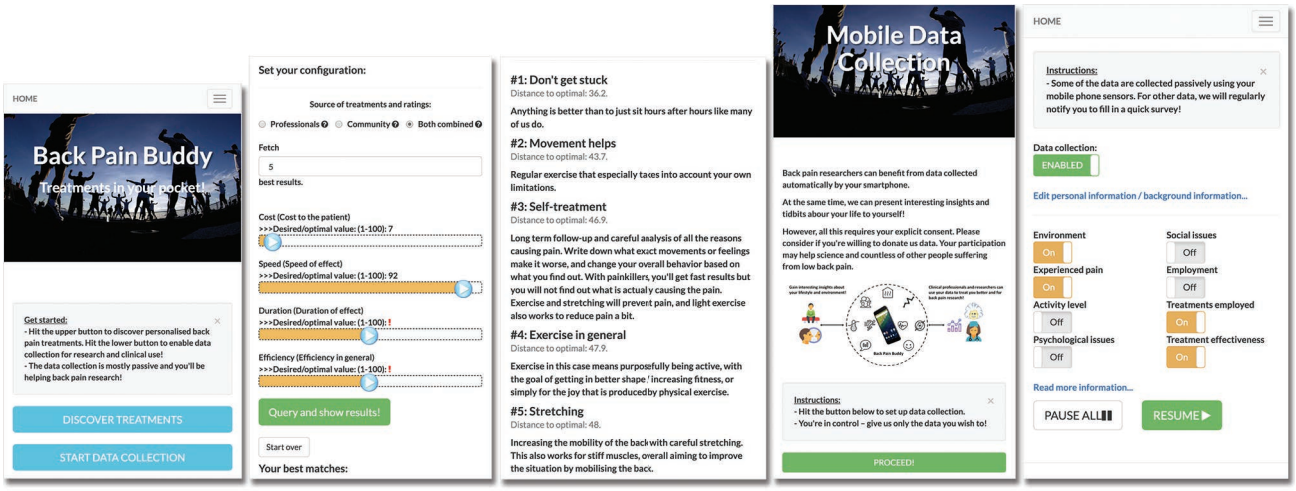

FIGURE 2. Screenshots of the "Back Pain Buddy" mobile application. Images reflect: (a) start screen, (b) decision support system to discover back pain treatments, (c) example list of retrieved treatments, (d) intro screen to data collection, and (e) on/off toggles to control the collection of a given type of contextual data.

which are all identified as highly relevant to LBP research:[8]

- Employment (documenting type of work, effects caused by LBP in the workplace, effects of LBP to employment situation)
- Environment (ambient information, weather, wind, temperature)
- Pain characteristics (type, intensity, speed, level of recovery)
- Demographics (age, gender, height, weight, country, etc.)
- Disability (type, extent)
- Physical condition (current activity levels, maintenance, body function)
- Psychological (effort of living, feelings of loss, disempowerment, worry)
- Social (psychosocial challenges, negative reactions by friends and relatives)
- Treatment (treatment burden, treatments being attended to)
- Medical history (records, past treatments)

Although the capabilities of mobile sensors are improving all the time, not all of these can be harvested passively but require self-reporting by the user.[10] For instance, sensors are great for inferring data on environment or a user's physical activity, but self-reporting is needed for gathering information on LBP's effect on work, or social and psychological conditions. For this, AWARE provides the Experience Sampling Method, offered via a simple query builder and questionnaire scheduler. Together, the 10 factors encompass a rich array of internal and external influences, factors about current activities, and other information that could be useful for LBP research and can be used to provide coaching in the form of lifestyle recommendations and encouragements. For instance, the comparison of a user's activity levels to those recommended by the user's personal care provider transparently provides useful information to both parties. Yet we emphasize that the user is in control: each of the data types is an optional feature in the application, users can simply turn the said collection feature on or off (Figure 2e).

STUDIES

Study 1: Opinions on Decision Support Component

To develop the LBP knowledge base (potential treatments, criteria, and their relations), we bootstrapped the system together with both clinical experts (doctors, physiotherapists) and non-experts (everyone else). This was conducted online, using a custom one-page Web application. On the site, users could contribute new treatments and rate others' treatment suggestions to the question: "What's a good way to

treat low back pain?" Inputting new treatments was enabled by standard HTML-form input fields, and rating values happened with slider inputs (one slider per criterion), very similar to the UI depicted in Figure 2b for obtaining decision support. For more information on the implemented system, we refer the reader to our previous work.[11]

Instead of tapping into an existing labor market (which would not provide us with the required expertise), as is the case in a typical crowdsourced system, we had to use a great deal of imagination to reach medical doctors and physiotherapists. We contacted a back pain researcher (who is a senior professor at a local university hospital) who was able to provide us with access to a national organization for doctors and physiotherapists specializing in back pain. Before initiating any communication to their mailing lists, we used the local collaborators to identify the four criteria that back pain patients typically find as important when looking for treatments. We did not want to have a dynamic list of criteria in the system, as the data collection needs rise linearly each time a new criterion is added. Nevertheless, the four most important ones, as judged by real practitioners, seemed like a reasonable compromise.

Using the email list of the national organization, we promoted our system to medical doctors and physiotherapists. Then, our local expert collaborators curated the options into a "gold standard" LBP treatment collection, and we sent this collection to the same mailing list for assessment. Then, to collect non-expert knowledge on LBP, the system was promoted publicly online in back pain–related Facebook groups and several relevant social media profiles. As a reward, we raffled one $100 gift card to a health-themed online market.

Then, for the actual DSS evaluation, we invited those who had contributed data to the knowledge base to use the now-bootstrapped decision support system. Their task was to play with it, get decision support, and simply see what it could do and what thoughts would arise when using crowdsourced knowledge on LBP. Everyone using the system was invited to complete an online survey, evaluating the value proposition, perceived trustworthiness, and overall usefulness. Second, Back Pain Buddy (the mobile application embedding the DSS component) was featured for a full day at a technology fair/exhibition of a local prototype "future hospital," which was managed by the local university hospital's research division. There, we interviewed final-year medical doctors and physiotherapists touring the fair as part of a course on future medical technologies.

Study 2: Acceptability of Contextual Data Collection

To study the acceptability and future issues of the contextual data collection component, we deployed surveys online to people with personal interest in LBP. We mainly used the list of our already-devoted participants from the previous user study. We listed the 10 contextual elements we are preparing to include in our data model as a Likert-scale, requesting users to consider their willingness to donate this data type for each item. Each item was ranked on a scale from 1 to 7 as "not at all willing" to "extremely willing." We clarified in the survey that not all data types can be collected passively using sensors but would require manual input from time to time. Another purpose of introducing the data types to the user was to make them think about the concept more deeply. We reasoned this would help them provide better open-ended commentary. We also included items about general acceptability of the concept, demographic data, mobile tech savviness, past personal experience with LBP, and open-ended items to provide feedback.

To further stimulate participants' thinking, we adopted elements from the Expectation Disconfirmation Theory (EDT), which is used in marketing sciences to predict consumer satisfaction with future products. EDT has been recently extended to predict technology trust and usage continuance intentions for technological products.[12] We adopted and described the following four factors to the participants.

1. **Ease of use:** the degree to which the sensing solution will require mental effort to use.
2. **Functionality:** the degree to which the solution will have the capability, functions, or features needed to accomplish its tasks.
3. **Reliability:** the degree to which the solution will continually operate properly, or will operate in a consistent, flawless manner.
4. **Usefulness:** the degree to which the user trusts that the solution is beneficial for its purpose.

Again, the items were presented as a Likert-scale where each item was ranked from 1 to 7, and 1 was equal to "not at all," and 7 was equal to "extremely" (for example, from "not

at all easy to use" to "extremely easy to use"). This section was also complemented with an open-ended item to provide feedback. Together with information on users' technology savviness, these items help predict issues in the system's future acceptability.[12]

RESULTS

Active Decision Support System: Value for All Stakeholders (Study 1)

Through the mailing lists that our collaborators gave us access to, we were able to recruit 65 experts (37 male, 28 female; ranging in age from 29 to 76 years; M = 53.0, SD = 11.4) to contribute 39 back pain treatments to bootstrap the decision support system. These were curated to 12 "gold standard" expert solutions that were then re-evaluated by the same expert pool. The experts inserted 610 unique ratings for the 12 treatments and four criteria that were already bootstrapped in the system by our collaborators.

There were 288 participants (63 male, 225 female; ranging in age from 23 to 75 years; M = 47.2, SD = 11.8) who contributed to the non-expert knowledge base. This crowd had an evident personal interest in the topic, as all but 18 of them had experienced back pain in their lives. The non-expert crowd contributed 69 new treatment ideas, out of which 56 were valid (we filtered out entries that were gibberish, such as "asdf" or empty submissions). Non-experts contributed 8,391 ratings for the available treatments.

There were 46 people (9 experts, 37 non-experts) who helped evaluate the actual decision support system after using it to discover treatments. In general, users perceived the DSS as highly useful in discovering back pain treatments (rating it an average 4.6, on a scale from 1 to 7). For an in-depth look into the collected data, we ask the reader to turn to our recent conference presentation.[11] We also conducted a lightweight qualitative analysis of the results. First, we loaded all the results in to a shared Google spreadsheet, in which two of the authors reduced the resulting set to items that were deemed as useful. Then, the same authors identified larger common themes independently, and finally again collaboratively discussed to finalize the themes and the items belonging to them. The usefulness of the system was supported by the qualitative findings:

> *P1, Female, 34: "The clinical care personnel get information of treatments that they do not know about, while the one with the pain learns about new options by others with pain."*

The inclusion of non-expert knowledge in the tool was seen as highly crucial for the system to be interesting: 30 respondents found the combined knowledge of experts and non-experts to be the most interesting knowledge source. The same sentiment was surprisingly shared between the experts as well:

> *P19, Male, 53, Expert: "Academic expertise alone does not provide a holistic view to the situation. It is good to understand what people in general think and how they experience the treatments to learn new viewpoints."*

However, critical viewpoints were also brought forward, especially regarding the ambiguity of the sliders used for indicating the desired criteria:

> *P11, Female, 50, Non-expert: "I would develop a better input mechanism than the slider. It is difficult. Traditional written scale works, as then there is no interpretation involved in giving the score."*

Mobile Sensing: Generally Acceptable, but with Reservations (Study 2)

We collected 192 survey responses (participants' ages ranged from 21 to 75 years; mean 46.1, SD = 12.2) to our survey on the mobile sensing concept. Of these, 88 respondents identified themselves as highly mobile tech savvy (scores 6 and 7 on a scale of 1-7 to the question "In your own assessment, how familiar are you with novel mobile technologies and their future potential?"). And 87 identified themselves as moderately savvy (scores 3-5); and 17 identified themselves has having as little or no savvy (scores 1-2). We also asked about participants' personal experience with back pain, and 61 identified themselves as heavily affected by back pain, 90 as moderately affected, and 41 as having little or no back pain affectedness.

Figure 3 plots people's willingness to allow data collection per each of the contextual data elements, and their enthusiasm to allow data collection in general. Below that, we plot respondent's future expectations toward the system's characteristics.

We observe that respondents were overall quite positive in allowing data collection, but that there were significant differences in the allowance of different data types (confirmed by a Kruskal-Wallis Test, $p<0.05$). More specifically, participants were more willing to donate pain characteristics

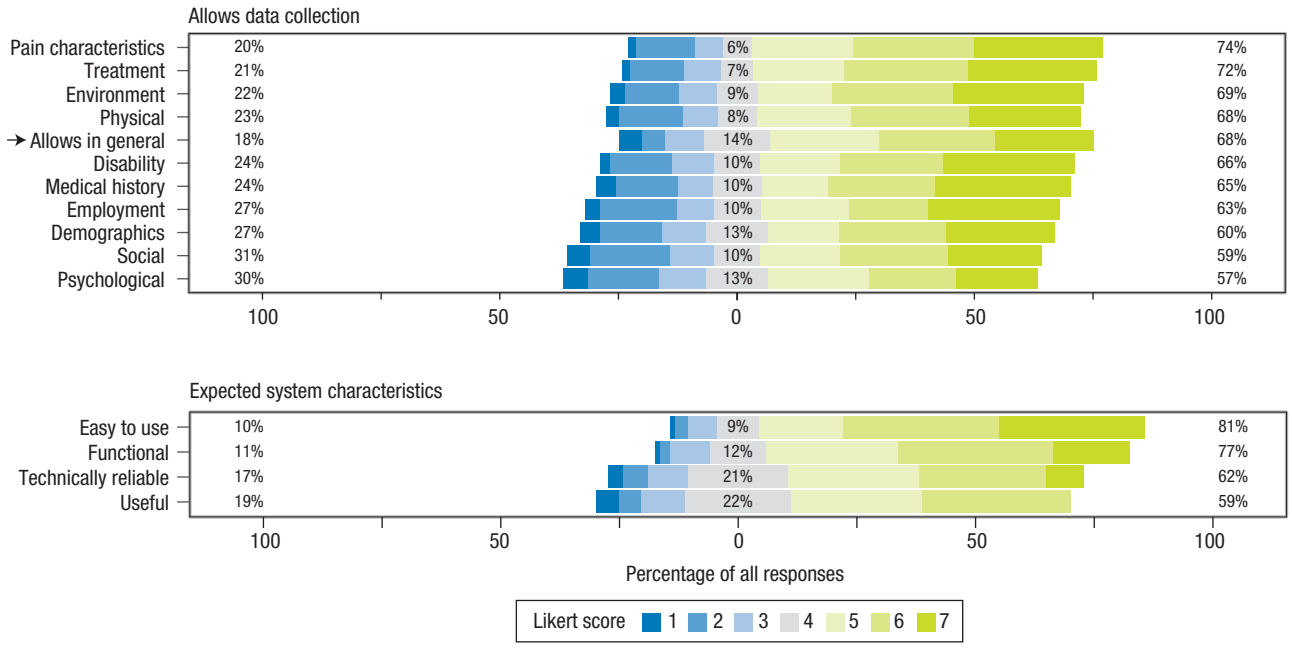

FIGURE 3. Top: data types plotted in order of willingness to donate. The arrow denotes overall acceptance of data collection. Bottom: expected characteristics of the final deployed system. The *x* -axes in the plots correspond to the percentage of responses.

and treatment data than data on psychological or social elements (Wilcoxon Rank-Sum Test for each of the four pairs, $p<0.05$). Interestingly, prior experiences with LBP, namely, having personally suffered from back pain, did not significantly affect data donation willingness. We discovered, however, that respondents' tech savviness affected the overall willingness to donate data (the item marked with an arrow in Figure 3). Those in the low-tech-savviness category scored an average of 4.3, whereas those in the moderate category scored 4.7, and those with high savviness scored 5.5. People with high savviness scored significantly higher than those with low or moderate savviness (Wilcoxon Rank-Sum Test for both, $p<0.05$).

Tech savviness also played a major role in future expectations. In all of the probed expected system characteristics (ease of use, functionality, reliability, usefulness), there were statistically significant differences between the tech savviness categories, as confirmed with Kruskal-Wallis tests ($p<0.05$). People with low tech savviness expected the future system to be less easy to use (average 3.8, on a scale of 1–7) than moderately or highly tech savvy people (5.4 and 6.1). As for functionality, the scores per savviness categories were 4.1, 5.1, and 5.7 (low-moderate-high tech savviness). Reliability scores were 3.9, 4.6, and 5.1 (low-moderate-high) and finally the usefulness of the system was anticipated as 4.6, 5.5, and 5.9 (low-moderate-high).

The overall response provided in the open-ended items toward the concept was excitement and welcoming. Some of the more optimistic comments are exemplified below.

> *P12, Female, 29: "I think it's only great if I can help others!"*

> *P97, Female, 39: "I'm willing to help in any kind of venture that aims for alleviating pain – and not just by giving more and more painkillers."*

Another 45 of the 192 respondents expressed major reservations toward the mobile sensing component that fell into three main categories: the idea of the collected data accidentally being leaked to the wrong parties; the system trying to exploit the data commercially; and ethics of the data collection in general. The following responses exemplify some of these concerns.

P109, Male, 28: "As long as the data stays only within the scientific or healthcare domains, I would donate my data."

P114, Male, 64: "Only a strictly sandboxed application has any chance to survive in the future 'cyber jungle.'"

ANALYSIS

In Finland, it is estimated that 80–90 percent of all people suffer from back pain during their lifetimes. This highlights pain's evergreen nature as the subject of empirical studies.[1] Our exploratory approach builds on capturing people's contextual data and using that to shed more light on the age-old and massively burdensome global problem of LBP. The long-term plan contributes to creating yet unforeseeable well-being assets that a greater understanding of people's lifestyles will yield. All this depends on ensuring the data are available and free for the scientific community to study.[6]

Back Pain Buddy is our contribution to the ongoing trend of leveraging the smartphone in the health domain.[3] It is a mobile end-user application that encompasses a powerful and trustworthy decision support system. As a component, it helps capture crucial contextual information as an entry point to a system that will provide data and insights to researchers and users alike on a global scale.

While we have a promising start, questions remain. How contributions be rewarded? How can the quality of incoming data be vetted? While long-term field studies with real subjects in their authentic everyday environments are not easy or cheap to conduct, they are well worth it in this case: LBP is a global problem. To this end, we also note that although the knowledge base collected by medical doctors should generalize relatively well outside Finland, there are a lot of questions about how to scale up the system to accommodate different countries, regions, and cultures. Here, we explore options such as prioritizing local data (national) or allowing users to filter data by country.

On the Uses of Contextual Knowledge

Our initial plans to exploit the collected contextual data span beyond just offering it to the LBP research community. First, when enough data exists on a Back Pain Buddy user, we can explore passive decision support in an attempt to nudge and coach the user toward healthier life choices. For instance, different countries have differing national recommendations in terms of recommended minimum exercise and activity levels or other optimal lifestyle choices that people should make in their life. Especially with LBP, keeping users informed about the benefits regarding activity and keeping up a "normal" life rhythm is beneficial.[4] Thus, we will build an automated solution to inform users when their activity levels drop below personalized recommendations, or if their activity patterns begin to decline over time. Second, when we bring the personal clinicians into the loop, for example by adding a field to the application where the clinician would simply enter her unique identification code to gain access to user data, we are able to provide patient data to the people who most need it, and care providers can also begin adding specific recommendations based on contextual data, for example recommendations about activity levels. All this, naturally, leads to a situation where we must be highly attuned to data management issues imposed by GDPR. For Back Pain Buddy, we rely on a modified back end of the AWARE mobile sensing toolkit,[9] an open source project that has been recently updated for GDPR as well.

Limitations

We also acknowledge limitations in this first exploration. First, the participants in Study 1 were mostly female, highlighting the challenge of studies where we simply recruit users online—there there is no easy way to guarantee an even sample of all genders. Further, Study 2 participants were recruited mostly from the same people who participated in Study 1. While this reduces the findings' generalizability, we argue that most of our system's end users are people interested in LBP in the first place. Recruiting among people who have already expressed interest in the topic is a suitable approach in this case (indeed, the two studies are very different, so there is no carryover effect).

A Roadmap Toward Open LBP Context Data

As our plan progresses, we continue to hear concerns from end users that introduce new design suggestions. For instance, we need to emphasize the fact that the decision support feature is a way to discover treatment suggestions and is not a replacement for visiting a doctor. The user is always responsible for her choices: Back Pain Buddy simply helps to discover treatments that can then be discussed with medical professionals. To this end, we also plan to tweak the UI to subtly steer the user to the treatments articulated

by medical professionals and show an additional warning dialog when the user wishes to discover treatments by non-professionals. The treatment knowledge base is indeed community-managed, and there are always quality issues involved in user-generated content.

However, we argue that the biggest upcoming challenge is a strategic one rather than a technical or design one. We must think long term, and not focus solely on immediate academic output. We are actively applying funding and looking for collaborators to focus on the obstacles described below.

- Unified definitions on how to describe the contextual data elements. Building a standard data collection scheme/language for storing the 10 contextual elements[8] will enable other research units to start contributing data and use other platforms and devices than our initial setup (Android + AWARE).
- Securing and designing the data storage/sharing facilities. As a starting point, we are using the open source AWARE server, modified to our needs. Here, crucial first issues to solve are how to ensure all contributed data adheres to the unified definition, and how to ensure automatic data quality checks. How can we allow clinicians access to a certain individual's data vault while keeping it closed to the rest of the world?
- Passive decision support based on sensed contextual data. We must investigate, in a series of studies, how to use the collected data so that it encourages the user to make better choices. Here, we also investigate how to best visualize users' activity levels and other lifestyle ingredients in contrast to national recommendations and other users.
- Scale up, initiate meaningful collaborations. Our collaborators at the Finnish Institute of Occupational Health can help us scale up the research, but before

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this, we need to run additional studies to validate the concept with real patients and people suffering from LBP.

Back Pain Buddy is a mobile application for providing decision support and collecting contextual data—both recognized gaps in LBP research and practice. Our results show that people are willing to donate their data, and that especially tech-savvy individuals expect no problems with adopting the application. This article introduces the idea, communicates promising first results to the community, and hopes to spark interest among interested international collaborators.

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The Online Trolling Ecosystem

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As trolling becomes inseparable from modern social media, a renewed effort is needed to unmask and abate the risks of this reality. A proposed taxonomy offers useful clarification.

The practice of using disinformation and misinformation to promote parochial agendas isn't new. Both have been used by tyrants, demagogues, dictators, authoritarians, and manipulators of every stripe for millennia. One thing that's new to our generation is the digital twist of Internet trolling. The effectiveness and increasing use of this tactic, highlighted in the 2016 US presidential election, justifies increased attention. An earlier *Computer* column[1] encouraged such attention, and we elaborate here.

Disinformation and misinformation both involve the distribution of false information, but with differing objectives. Disinformation involves the intentional planting of false information to conceal truth or deceive the audience, especially by state actors, whereas misinformation is more generic and relaxed regarding intention, concealment, and source. For our purposes, we intend the definition of disinformation to include not just governments but also political groups, ideological movements, and other social entities. Disinformation is more pernicious, being necessarily both intentional and deceptive in its pursuit of social engineering goals. Although some trolling might be without willful deception (as in the case of mistaken "true believers"), disinformation is the more natural ally of trolling and is thus our focus.

The topic of disinformation is both complex and varied: it's complex owing to its convoluted methods; it's varied because of its different practitioners and contexts. It can be used to enlist support, confuse, de-legitimize, defame, intimidate, confound, escape detection or blame, avoid prosecution, and on and on. The public relations strategist uses disinformation in different ways than the tyrant owing to the latter's assumed greater imperviousness to punishment or retribution. Similarly, the ideologue's use of disinformation is different from that of the corrupt politician. Disinformation techniques and content vary with the purpose, targeted demographic, medium, and social networking platform.

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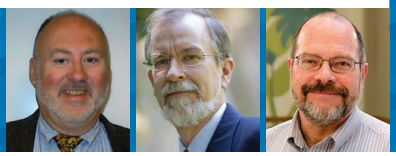

These issues apply to trolling as well. Consequently, we've developed a partial taxonomy to better characterize trolling's many manifestations. This is an appropriate time for a taxonomy, for trolling is mature enough now to reveal interesting patterns and suggest future trends and defenses.

ROOTS AND MISSING LINKS

Trolling is confirmation, in a sense, of a fundamental flaw in the notional roots of the modern Internet-enabled Web. Those roots are typified by, for example, Paul Otlet's Mundaneum system, implemented in 1910 to collect and categorize all of the world's important knowledge (www.mundaneum.org/en); H.G. Wells's notion of a World Brain, outlined in a 1938 collection of essays and addresses with that title; and Vannevar Bush's Memex system, described in his influential 1945 article "As We May Think."[2] Bush envisioned a collective memory system that would advance a knowledge explosion by serving up the corpus to anyone on demand through associative indexing and browser history-like "paths" not unlike the use of hypertext to organize the Web. As was customary in the early information age, Bush was driven by the simultaneous desire for ease of information access and avoidance of information overload. He wasn't concerned about data reliability and source authentication.

As it turns out, this overly simplistic and naive view of the information access challenge has been perpetuated ever since on the Web. To wit, subsequent work on metadata standards, including the Dublin Core elements (http://dublincore.org/documents/dces; https://tools.ietf.org/html/rfc5013), completely ignore any measure of authenticity and reliability. The closest metadata elements would include oblique terms such as "provenance," "conforms to," and "is referenced by." This deficiency has been carried forward in such subsequent document type definitions as the Open Source Metadata Framework and the Resource Description Framework. To overcome this deficiency, more user control is needed—perhaps a user-driven metadata insertion tool for elements like "suspect," "disproved," and "content warning," or some sort of Bayesian trigger to deal with today's fake news and alt-facts. Otherwise, the 21st century's spin on Bush's vision might progressively become "As We May Deceive."

The study of disinformation, from an information-theoretic point of view, has thus far regrettably been at best occasional and informal. We have in mind, for example, contributions by David Martin and H. Michael Sweeney on disinformation[3,4] and traits of disinformationists.[5] While informative, especially with respect to the current political landscape, these works are largely anecdotal, lack examples, and aren't directly related to trolling. *Spy the Lie*[6] provides a practical guide, with examples, for detecting deception, including an analysis of behavioral cues that might betray the act. A rough equivalent for social media deceptions is sorely needed. Alas, self-published contributions on the Web, and those from the popular press, fail to do justice to the full impact of disinformation generally[7] and trolling in particular.[1]

TROLLING AS AN IDEOLOGICAL WEAPON

Online trolling as a form of communication is readily weaponized. Its ease of use and accessibility to anyone with an Internet connection virtually eliminates entry barriers. Its appeal as a communication tactic to tyrants, demagogues, and manipulators of all kinds is obvious. It thus fits comfortably within such models as pathocracy (rule by the maladjusted, psychopaths, narcissists, and the like)[8] and kakistocracy (rule by the least competent)[9] as an effective tool of online manipulation, obfuscation, and deceit. It's no surprise that trolling has become increasingly popular.

The relationship of trolling to disinformation and politics has reached a modern zenith owing to the current US administration's relaxation of the norms and expectations of veridical communication and the Russian government's embrace of trolling. That said, the White House's proneness to misinformation and even outright disinformation is a symptom of a more general social problem—namely, political emotionalism, in which facts are too often considered less of a foundation and more of a hindrance.[10,11] That trend manifests itself in a tolerance of falsehoods under the guise of alt-facts, the inability to distinguish confirmable statements from beliefs and opinions, and an unreflective commitment to ideology-based and simplistic slogans, catch phrases, sound bites, formulas, and beliefs. Social scientists have developed theories of social dominance, authoritarianism, and instability that explain some these characteristics in terms of group behavior, economics, and social hierarchy.[11–14]

> Online trolling is readily weaponized—it fits comfortably within pathocracy and kakistocracy as an effective tool of online manipulation, obfuscation, and deceit.

WHY DISINFORMATION? WHY TROLLING?

Disinformation generally and trolling specifically are expedient ways to manipulate public opinion. Authoritarians of all generations understood that sound and reasoned argument isn't sufficient to exercise control over others. Something more powerful but short of force is needed. Such machinations, to be effective, must be carefully engineered and targeted, an objective often unachievable through reasoned public debate. If politicians were to rely on logical debate, free of manipulative rhetorical devices, public consensus might be influenced by the merits of the arguments themselves when interests, often authoritarian or domineering, wish to avoid this.

> Disinformation and trolling are expedient ways to manipulate public opinion. They can polarize issues to exploit a human bias toward binary choices.

Carefully crafted disinformation campaigns and trolling efforts can be instrumental in achieving the desired effect. They can artificially polarize issues to exploit a human bias toward binary choices—seeing the world in black and white, big and small, rich and poor. This is related to what Hans Rosling calls the *gap instinct*.[15] Its appeal must follow in part from the cognitive simplicity of binary distinctions, much as we experience with true/false questions on exams. Other things being equal, cognitive effort is lower on true/false than multiple-choice questions because there's less to think about.

Disinformationists and trolls seek to create a sense of extremes where the extreme they tout is cast in a more appealing way than the alternative. In order to force the information consumer to the desired extreme, they use lies, prevarications, untruths, alt-facts, unlikely theories, distortions, ad hominem attacks, and other rhetorical devices as part of a Machiavellian propaganda or "messaging" campaign to create the desired artificial duality in lieu of the more nuanced and reality-based presentation that would result from clear-headed analysis. Modern online disinformation and trolling campaigns functionally resemble phishing attacks in combining a modest amount of computing and networking skill to cloak the real goal and lure the target using perception management (manipulating the public into thinking they perceive something they don't, or vice versa) and social engineering (motivating the public to do something they otherwise wouldn't have done).

In his book *Factfulness*,[15] Rosling describes how evolutionary traits like hard-wired fast-response brains produce simplistic world views that discourage adequate reflection and deliberation for decision making. He identifies 10 evolutionary "instincts" that no longer serve humanity well in separating truth from predatory fiction. Such instincts should be critically discussed as part of college-level general education, if not in high school. Primary education should provide practical skill in BS detection, right along with the 3 Rs. Call it the 4th R: reality checking.

A TAXONOMY OF TROLLING

Online trolling has matured to the point that we can discern some evolutionary patterns and future directions. The value proposition is obvious from the 2016 US presidential election: low-cost, potentially high-impact voter manipulation through micro-targeting. Political scientists and others continue to study the degree to which trolling influenced the vote. UK-based Cambridge Analytica executive Mark Turnbull took credit for playing a key role in Donald Trump's win,[16] and there's now sufficient concern over the use of trolling by foreign governments to undermine US federal elections that, as part of the Mueller probe, the US Department of Justice indicted the Russian trolling factory, the Internet Research Agency, for 8 federal crimes[17] as well as 13 Russians and 3 Russian companies for attempting to subvert the 2016 election.[18]

One thing is certain: online trolling is here to stay. Even if federal legislation were passed to outlaw it, problems like reliable cyber-attribution[19]—at least that which is admissible in court—will provide trolls many avenues to circumvent whatever laws might be enacted.

So what's the future of online trolling and its containment? We offer the following informal taxonomy as a means to focus our response.

Provocation trolling. To elicit a particular response, such as hostility, from participants of an online forum. For example, in the "Reactions" section of a Yahoo! article about a 20-year-old Guatemalan woman shot dead in Texas by a US border agent, many top comments seemed intended to spark a flame rather than shed light. For example, the first comment was "Medal of Honor!!!" (http://www.webcitation.org/710m5n0WF). Similarly, in an online discussion, blaming liberals or conservatives for a tragic or controversial incident will likely cause some offended readers to lunge for the bait.

Social-engineering trolling. To incite participants to activities they normally wouldn't have undertaken—convince readers to join an organization, send a donation, observe a boycott, vote for/against a candidate, and so on.

Grooming trolling. Sending messages intended to insinuate the sender into the mind of the recipient as a slippery slope to further persuasion. Radical organizations are notorious for

using this variant of social-engineering trolling to recruit members: ISIS was widely noted for "fishing" for new members on Twitter this way, and US extremist groups are frequently noted for using this tactic.

Partisan trolling. To use social media surreptitiously to achieve political ends. Here's where the heavyweights really get involved. For example, trolling has been exposed as an important component of Russia's "firehose of falsehood" (see below) propaganda strategy, especially in the recent US presidential race.[20]

Firehose trolling. High-volume, rapid, continuous trolling without concern for consistency. Apparently a favorite of Russia, it focuses not on promoting a particular position or viewpoint but on divisiveness for its own sake. For example, according to Charles Clover, Aleksandr Dugin's book *The Foundations of Geopolitics* is influential at the highest levels of the Russian government and "assigned as a textbook at the General Staff Academy and other military universities in Russia."[21] (A good English translation of the entire book isn't yet available.) Clover quotes Dugin as writing, "It is especially important to introduce geopolitical disorder into internal American activity, encouraging all kinds of separatism and ethnic, social and racial conflicts, actively supporting all dissident movements—extremist, racist, and sectarian groups, thus destabilizing internal political processes in the U.S." Trolling is certainly well suited to this activity. And it can be tough to counter. Christopher Paul[22] recommends against trying "to fight the firehose of falsehood with the squirt gun of truth," but fails to provide fully satisfying alternatives.

Ad hominem trolling. Defaming or discrediting individuals or groups to delegitimize their positions without engaging them on their merits. The following snippet from an exchange on an email list exemplifies this.

> *ML: [Controversial claim] Anybody who claims otherwise is ignorant, uninformed, or lying.*

A naive respondent might be whiplashed at this point because a counterargument, reasoned or not, has already been pre-characterized as ignorant, uninformed, or a lie. The best response is probably to simply point out the rhetorical device used here, as respondent PD does next.

> *PD: Ooh—is this the choose-your-own-ad-hominem part of the show?*

Yet even this response is hobbled because the discussion has now been diverted into a rhetorical cul-de-sac that saves ML from losing the argument.

Jam trolling. Disrupting a discussion or communication channel with high message volume (the trolling equivalent to a DOS attack). Technologically, automated trollbots will make this an increasing problem.

Sport trolling. Trolling for the self-gratification of the troll (just for the fun of it).

Snag trolling. Evoking responses to satisfy curiosity. One of the less toxic varieties, this nevertheless tends to divert and obscure.

Nuisance trolling. Derailing the thread of an online forum (blog, chatroom, and so on) for no other reason than to irritate other participants. A variant of sport trolling.

Diversion trolling. An insidious tactic for blocking legitimate communication by diverting a thread in a direction that's misleading, irrelevant, false, and so on. Thus, a discussion about rising crime rates could be diverted by citing a small community that hasn't had a murder in 20 years, or a discussion about falling crime rates could be diverted by mentioning a recent crime.

False-flag trolling. Pretending to be of a group or hold an opinion that the troll actually opposes, and presenting a message intended to make that group or opinion look bad. This is one of the harder forms of trolling to detect, because the writer could in theory really have the opinion claimed but not realize how his obnoxiousness is creating the opposite of the desired effect. For example, a type of robocall used in political campaigns pretends to support one candidate but is so annoying that it actually helps the opposing candidate.

> Problems like reliable cyber-attribution will provide trolls many avenues to circumvent whatever laws might be enacted against trolling.

Huckster trolling. The online world's equivalent to street vendors. A typical example: "Loved your insightful post! Smash financial barriers with our personalized method. Click now to unlock YOUR potential!" Here's where advertising meets trolling.

Amplification/relay trolling. This occurs when one trolling venue is used to amplify the message of some other source—for example, a politician using Twitter to repeat something reported on *Fox & Friends* or *Morning Joe*.

Rehearsal trolling. Baiting opponents to respond in order to reel in the "fish," or victim, to practice arguing with. The more annoyed the respondent, the more energy that person will expend

providing the spirited practice the troll wants. The troll thus hones debate skills for uses like higher-stakes trolling later.

Proxy trolling. Using intermediary trolls to do the heavy lifting. De rigueur for large organizations, which hire people to do it.[23] One application is astroturfing: promoting a position, product, person, and so on for which there's little awareness or support by making it look like that entity is widely approved of. Websites and organizations set up by special interests but given names like "Citizens for X" are standard examples. Proxy trolling provides rich opportunities for all manner of resource-rich, unscrupulous actors.

Faux-facts trolling. Deliberate spreading of fake news, alt-facts, and other lies under the guise of truth. To fight this type of trolling, refereeing organizations, typified by the well-regarded Snopes (https://www.snopes.com/about-snopes), are a socially valuable, even essential institution. We can expect large organizational trolls to sow chaos and confusion with fake fact-checking organizations of their own.

Insult trolling. Insults spark responses that drain the target's energy. They also make the target look bad and are demoralizing.

PR trolling. Making the troll or the views the troll is promulgating look good rather than attacking others. For example, the troll could make a claim and unverifiably cite a brother-in-law "who was there." But the most common example is to state approval of another text. It's easy to upvote another troll's message, or respond to a posting with "Right on!" or "Thank you for saying what so many know but are afraid to say." This boosts persuasiveness via a bandwagon effect.

Chaff trolling. Sending messages that are essentially content free and thus vacuous. For example, on social media platform Quora someone claimed that a relative assigned to help guard former president Obama said that the president was "... fake as [expletive deleted]." One might well question if this relative really existed, and if he did, whether the quote was accurate. Yet consider also the word "fake": here it carries little if any information about its subject but is an effective insult for the many unsavvy readers.

Wheat trolling. High-quality trolling using content that's hard or impossible to refute—for example, a cleverly doctored photo or text incorporating seemingly well-sourced "facts." Some lies contain their own logical inconsistencies; others smell bad only to a domain expert.

Satire trolling. Good satire cuts deep. It's hard to create and even harder to generate automatically. Thus, effective as it is, satire trolling will likely remain a relatively small player in the trolling world.

> A trollbot has a much easier time passing a Turing test than a chatbot.

TURING TROLLBOTS

A trollbot is simply an automated troll. Like a chatbot, it generates texts computationally. Unlike chatbot texts, trollbot output possesses markedly weaker requirements for coherence and continuity from its context. Consider, for example, a program that uses a simple bag-of-words algorithm to detect tweets or other posts critical of a particular position or public figure. It then posts replies randomly picked from a set of stock replies like "You tell'em baby!" and "That's SO right."

Informally, let's refer to a trollbot that's indistinguishable from a human troll as a Turing trollbot—one that has passed the trolling equivalent of the Turing test. A computer-controlled chatbot passes the traditional Turing test if and only if the human tester cannot distinguish the chatbot from a human. Compared to a chatbot, a trollbot has a much easier time passing—the weaker constraints on trolling make it so. Sure, there are human trolls for whom sophisticated trolling is an unsavory art form that would be hard to imitate, but a Turing trollbot need only mimic the lowest-common-denominator human troll to masquerade as a real person.

The concept of the Turing trollbot is increasingly recognized.[24] The hardest technical aspect of primitive Turing trollbot design is sneaking through smart filters like CAPTCHA. In fact, such trollbots could soon emerge as easily downloaded freeware apps. But primitive Turing trollbots are just a start. As we were writing this article, IBM unveiled its Debater system,[25] which successfully took on a college debate champion. This is a much greater challenge than deploying successful trollbots, which can be ever so much more efficient and economical than a paid human.

With armies of well-nigh undetectable trollbots on the horizon, what's one to do against this threat? One approach is to simply ignore outright all controversial social media comments—that might protect individual readers. Another approach is mass immunization. The simplest way to ensure public health is for enough people to reply to suspected troll messages by shining a light on them. "Are you a troll?" might serve not just as a comment but as a warning and reminder to readers who otherwise might have overlooked the possibility. But one way or another, society must

develop strategies to reduce trolling and trollbot effectiveness.

Research is also needed to investigate the potential for automatic trolling detection software. What kinds of trolling are undetectable? What kinds have already been detected, and who are their sponsors? We also need to educate the public. An increasingly necessary goal of primary education is training people to approach social media statements with suspicion, especially when it comes to bias and misinformation. The Internet—through social media and fake news outlets—has saddled us with the biases of those seeking to manipulate others through new forms of information corruption such as source displacement/concealment, decontextualization, and the like. Where the traditional measures of networks were in terms of value,[26,27] a new and useful measure of networks is their potential for abuse.[28]

POLITICAL TROLLING

In addition to the computer and networking context, online trolling must be understood in a geopolitical context,[29,30] especially with respect to its utility in international competition and rivalry. For example, a measurable amount of the identified external political trolling used to influence the outcome of the 2016 US election appears to have been either sponsored or inspired by Russia. China certainly has the capability for effective political trolling as well. As time passes, more countries will inevitably engage in it as a useful and cost-effective way to project influence. Free societies are the most susceptible to political trolling because in those countries mass opinion is a strong driver of national policy.

Moreover, polarization and partisanship have been increasing for decades.[11,31–33] Trolling's utility is related to the political divisiveness of the target society. As trolling and other ways of abusing social media and networks evolve, the current deficiencies in teaching disinformation tactics widely as an important civic skill will become more apparent. Our children, like all too many adults, lack the basic skills to look upon divisive, emotive communication critically. This is a severe educational shortcoming that promises to exact a considerable toll on democratic systems.

Society needs to understand why people troll. It seems to be one of many addictive behaviors mostly afflicting alienated young males and enabled by the anonymity and easy accessibility of the Internet, much like overindulging in online porn or videogames (https://www.quora.com/Whats-it-like-to-be-an-Internet-troll). But perhaps it's not as important to understand the psychology underlying trolling as it is to avoid being manipulated by it. As Lee Edwin Coursey[34] advises,

The next time you see a hyperbolic social media post that confirms your worst fears about people of a particular race, gender, religion, or political affiliation, your first reaction should be, "nice try, Russian troll," rather than "OMG I MUST REPOST THIS EVERYWHERE!!!" Learn to take a breath and pause before you immediately like, retweet, or share divisive messages from obscure sources. Be especially wary of emotional manipulation. Most importantly, fact check yourself before spreading information designed to foment outrage and factionalism. Remember that the phrase "Russian disinformation campaign" does not describe some outdated method from a bygone era, but instead represents an active, effective tool being used against you right now.

The cognitive load for detection and prevention is considerable, even for a coalition of the willing to do so. There's little cognitive load for tribalists because of illusory feelings of superiority, anosognosia (critical lack of self-awareness), and other cognitive biases. Part of the threat (and hence the value) of trolling is that so many independent-minded people don't have the time and energy to check facts or verify claims, while tribalists and authoritarianist followers don't feel the need.

As a consequence, trolling is convenient fodder for the gullible. It's free, self-reinforcing propaganda that unifies true believers and confuses or obfuscates issues sufficiently to manipulate fence-sitters. The game changing potential lies with the latter (for example, the 40,000 votes in three states that effected the Electoral College outcome of the 2016 US presidential election). This is where trolls and other social media manipulators see the real payoff. It's for this reason that so much trolling content tends to be shocking, distressing, offensive, and the like—it's designed to arouse the passions of the recipient while not lending itself easily to deliberation. The more independent fence-sitters can thus be stimulated to action or opinion without benefit of the reflection that would call into question the validity of the message or stimulate thoughtful evaluation. Fact checking, introspection, and analysis work against the interests of trolls. In this way, trolling is similar to a military campaign where the goal is action without debate.

Free societies are the most susceptible to political trolling because in those countries mass opinion is a strong driver of national policy.

We might take a lesson from Winn Schwartau's Time-Based Security Model

in this regard.[35] The model posits that a security system can be effective only when the time it takes to detect a security breach and mitigate against the threat is less than the time it takes for the security breach to achieve its objective. There's a parallel when it comes to mitigating against the effects of abusive social media. For it to be effective, the detection time must be near zero because the reaction time required to re-tweet, forward, and so on is negligible. The parallel with trolling is that the troll is focused on achieving quick results before second thoughts might be raised.

It's worth adding that trolling's ability to promote division can also be used to nurture social reform and is thus a doubled-edged sword for authoritarian and totalitarian states. For that reason, such states must carefully monitor and control trolling and related digital media manipulation tools within their borders.

New though it is in the toolbox of Machiavellian kingpins and social misfits alike, the effectiveness of trolling ensures that it'll continue to play an important role in future politics.

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A Role for IEEE in Quantum Computing

Erik P. DeBenedictis, Sandia National Laboratories

Will quantum computation become an important milestone in human progress? Passionate advocates and equally passionate skeptics abound. IEEE already provides useful, neutral forums for state-of-the-art science and engineering knowledge as well as practical benchmarks for quantum computation evaluation. But could the organization do more?

IEEE is uniquely positioned to help the public and policymakers understand progress and plan the path forward. If quantum computers are destined to be a big business, students will need to be trained in the new technology so as to become part of the workforce that expands the economy. Commercial success will depend on an open and collaborative dialog on engineering, technical standardization, and policy development, which coincides with IEEE's core businesses: conferences, publications, and standards.

Over the past 35 years, our success in understanding quantum computing has revealed its potential as a new, disruptive computing technology. This technology is based on quantum physics and might solve classes of problems that are intractable today. The physics has been demonstrated to the level of the very earliest "classical" computers, and it's now time to see whether quantum computers can be manufactured at a larger scale and used widely, placing the topic squarely in IEEE's mission space.

DEVELOP YOUR OWN VIEW ON QUANTUM COMPUTING

Instead of trying to pitch quantum computing or convey skepticism about its feasibility, let me explain the key issue so readers can form their own opinions.

Quantum computing is not expected to make an incremental advance over classical computers, like Moore's law, but might transform the notion of what is computable.

The advance from Roman numerals to place-value number systems thousands of years ago could serve as

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precedent for the transformation. In modern computer terminology, place-value numbers scale better to complex arithmetic operations. For example, humans can multiply and divide with place-value numbers, while these operations are impractical with Roman numerals. However, the ancients did not know what they were missing because they did not multiply and divide very much. The resulting increased ability to do arithmetic triggered the creation of entirely new areas—science, engineering, business, and products such as computers—that were not anticipated when place-value numbers were devised.

A quantum computer's qubits work like lottery tickets where you pick numbers first and there's a drawing afterwards—like Powerball but with rules dictated by quantum physics. In a quantum computer, the lottery drawing is called measurement and it labels losing lottery tickets with 0 and winning tickets with 1, thereby turning qubits into bits. However, quantum computing takes place before the lottery's drawing when it has not been decided whether a ticket will win or lose. A quantum computer's gates have the effect of swapping some of the picked numbers between pairs of lottery tickets, creating a computational model based on correlated probabilities.

Now think about computations you've done with pencil and paper or programmed on a computer. How often have you thought, "Gee, this computation would be much more efficient with predrawing lottery tickets instead of numbers." If you're anything like me, you've never thought that. Yet it's mathematically indisputable that this type of computation is vastly more efficient than today's computers for some problem classes.

Place-value numbers expand the meaning of a digit based on where it appears in relation to other digits, yielding more efficient arithmetic. Likewise, a qubit can compute with correlated probabilities before the qubit is turned into a bit. Quantum computing will trigger the invention of new computer applications, but nobody knows whether there will be enough of them to transform society. The benefit of qubits over bits might become common knowledge eventually, but right now we need a few engineers to figure it out for the first time.

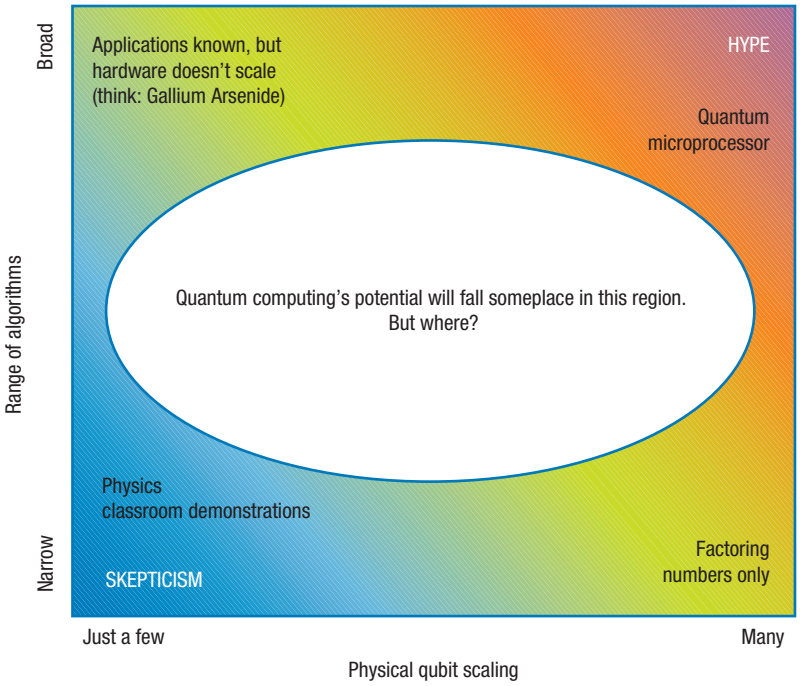

Figure 1. One hundred years from now, quantum computing will be at a point in the oval, sandwiched between four impossible scenarios.

SKEPTICISM, REALITY, AND HYPE

A hundred years from now, quantum computing will likely have found a position in the large white oval shown in Figure 1, sandwiched between four limiting scenarios that will ultimately be dismissed as hype or skepticism.

Figure 1's vertical axis represents the ultimate number of useful quantum algorithms, or algorithms best expressed using the predrawing lottery tickets described in the previous section. We know quantum algorithms are superior for factoring large numbers, yet theory precludes a quantum computer from being the equivalent of a microprocessor with an astronomically high clock rate. Nobody knows how many applications will eventually run best on quantum computers, particularly if society changes in response to quantum computers' ability to solve new problems.

Figure 1's horizontal axis represents our ultimate ability to engineer large-scale quantum computers. Research laboratories have created gate-type quantum computers with 50–100 qubits, and a larger number of qubits for quantum annealers (although annealers are less capable per qubit). However, this is much less than the billions of active devices in today's microprocessors.

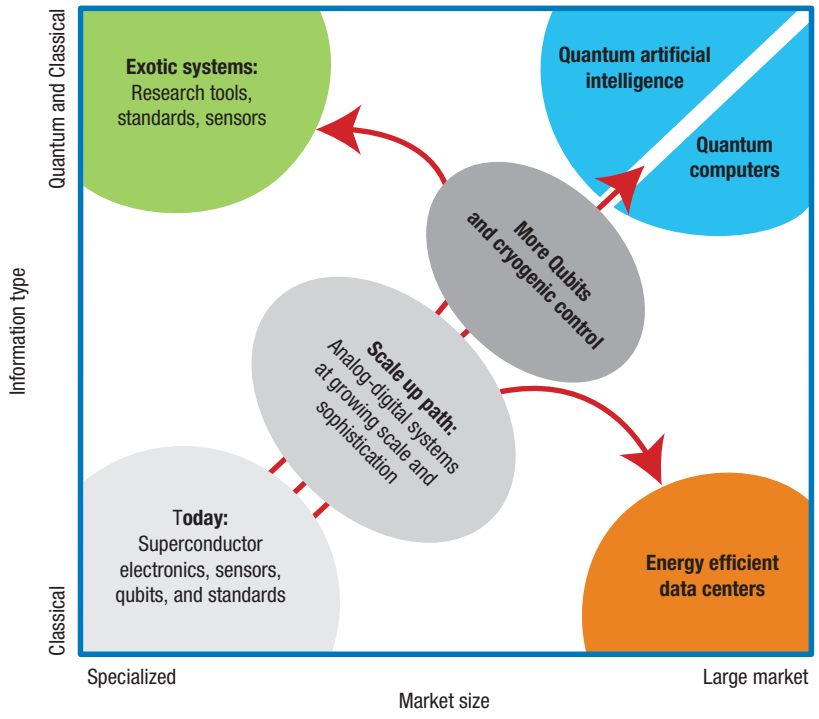

Figure 2. Top-level structure for a superconductor electronics and quantum information processing roadmap.

The main debate today concerns where reality lies on the diagonal between skepticism and hype in Figure 1. However, the other diagonal must be considered as well. It's possible that many important quantum algorithms will be found, but the implementation of quantum computers will remain difficult (like, for example, Gallium Arsenide semiconductors, which were eventually set aside). Alternatively, we might master the technology behind quantum computer hardware, but the range of applications will remain limited to narrow problems such as factoring numbers.

THE QUANTUM-CLASSICAL INTEGRATED ENTERPRISE

We don't know whether quantum computing will withstand the test of time, but we're learning the scope of the enterprise if it does. Quantum computing's ecosystem was addressed at a November 2017 workshop—the 20th Biennial US Workshop on Superconductor Electronics, Devices, Circuits, and Systems in Santa Cruz, California—which included working sessions on a growth path. I based Figure 2 on this workshop's discussions, and this figure and the ideas it depicts have become a new branch of IEEE's International Roadmap for Devices and Systems roadmap for quantum computing and its ecosystem.[1]

Until recently, quantum computing breakthroughs were mostly physical science research projects demonstrating particular qubit types, many based on superconductor Josephson junctions. These operate in a cryostat at remarkably low temperatures around 0.01 K and interfaced to the outside world through a handful of coax cables. These results are in stark contrast to current computer engineering practice, which addresses chips, architecture, manufacturability, design tools, and software at the scale of billions of devices.

Future quantum computers will integrate true quantum components with classical control systems, parts of which operate at very low temperatures. This hybrid system will need to adapt many aspects of computer engineering to a previously obscure branch of electronics called *cryoelectronics*. Cryoelectronics principally includes superconductor electronics based on Josephson junctions and semiconductors operating at low temperatures.

The gray structures in Figure 2 are an evolutionary path whereby today's handfuls of qubits and chips with around 100,000 Josephson junctions can scale up; become better integrated; and address practical issues in manufacturing, analog signaling, and design tools. These intermediate systems might be useful for science experiments and niche applications, but are not expected to have large markets.

The colored structures in the corners of Figure 2 represent applications or markets that could split off eventually, including the following:

- Truly exotic systems that might advance society even if produced in small quantities, such as spacecraft sensors and gravity wave detectors.
- Energy-efficient classical computers for data centers and supercomputers, perhaps exemplified by the current IARPA C3 program.
- Quantum computers, which will be a hybrid of quantum and classical control components. This option is divided into quantum computers running human-created algorithms and quantum machine learning,[2] the two divisions probably having different architectures.

HOW CAN IEEE HELP TECHNICALLY?

Today's qubits are unreliable or noisy as a result of imperfect materials and manufacturing, meaning they can only perform a few operations before making a mistake. For example, an

ion trap quantum computer whose operations were successful 99 percent of the time—corresponding to a 1 percent error rate—warranted a Nobel prize in 2012.[3] CMOS has an error rate of about 10^{-21}, so there's a lot of room for improvement.

IEEE's quantum roadmap effort should be able to assist these improvements.[1] Starting in the mid-1990s, the semiconductor industry managed the historic rise of CMOS in part through the International Technology Roadmap for Semiconductors, whose principal purpose was to identify the materials science and device physics research necessary to maintain the expected rate of progress. Now called the International Roadmap for Devices and Systems, this roadmap has become part of IEEE's Standards Association (IEEE-SA) and might be able to extend its historical role in orchestrating the development of technology to include quantum computers.

Creating a roadmap requires knowing where the road leads and measuring how fast you're going. The next milestone on the road will be *quantum supremacy*—the point at which a quantum computer can solve a problem not possible for any classical computer.

IEEE-SA also has an effort called P7131 that is developing a metric to measure a quantum computer's capability or quality (http://standards.ieee.org/develop/project/7130.html). At the time of this writing, major research organizations tout the number of qubits in their research-grade quantum computers, such as 49, 50, and 72 qubits, implicitly using qubit count as a metric. Although IEEE-SA will follow a consensus-based process to define a quantum computer metric, I can report that current discussions include combining the number of qubits, qubit stability or operational reliability, and architectural efficiency.[4] There's also an understanding that benchmark programs will be required at some point, or the equivalent of Linpack for the TOP500 Supercomputer list.

HOW CAN IEEE FACILITATE COMMUNICATIONS?

IEEE's main service to the community involves conferences and publications, both of which evolve to embrace new technologies. The Rebooting Computing initiative, which sponsors this column, began in 2013 and annually hosts the International Conference on Rebooting Computing (icrc.ieee.org), which is a venue for reporting research results that include quantum computing. The same event hosts an industry summit for business opportunities.

The industry summit has become a forum for quantum computing announcements, a role its hopes to keep and expand. There's a plan to include a quantum "competition," similar to the Gordon Bell award or the TOP500 list for supercomputers.

I've been in contact with various IEEE societies and councils and have noted their interest in supporting conferences and special journal issues on quantum engineering, but further news on these will have to wait until calls for papers are issued.

An IEEE standard P7130 is also being developed to establish common terminology and notation for quantum computing concepts (http://standards.ieee.org/develop/project/7130.html).

It is becoming increasingly likely that quantum computers will succeed in factoring large numbers and force a change in cryptographic codes, such as the well-known https. However, it is possible that the underlying technology will find other uses, ultimately having a transformative effect on society like the invention of place-value arithmetic. Reality almost certainly lies in between. Given the magnitude of the consequences and the fit to IEEE's technical area and member skills, I'm suggesting that IEEE consider a carefully thought out approach to figuring where, exactly, reality lies between the extremes. C

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User Data Privacy: Facebook, Cambridge Analytica, and Privacy Protection

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With the revelation that Facebook handed over personally identifiable information of more than 87 million users to Cambridge Analytica, it is now imperative that comprehensive privacy policy laws be developed. Technologists, researchers, and innovators should meaningfully contribute to the development of these policies.

The discovery that Facebook gave unfettered and unauthorized access to personally identifiable information (PII) of more than 87 million unsuspecting Facebook users to the data firm Cambridge Analytica[1] has fueled growing interest in the debate over technology's societal impact and risks to citizens' privacy and well-being.[2] It is clear that national governance institutions demonstrably lack the ability to anticipate technology's future impact on the rights and duties of its citizens, much less its impact on the structure of society, ideological divides, and political schisms among its citizens and the expansion of identity politics promoted by isolated social and news media echo chambers.

The ubiquity of data gathering, storage, and analytics on our devices, systems, applications, and social media platforms—aimed at

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personalizing experiences, optimizing sales, and maximizing return—have been disruptive in shaping the global economy, the flow of ideas, and access to information that resulted in the advancement of innovation around the information marketplace. This risk is further exacerbated by the fact that Internet of Things (IoT) devices are becoming more integrated into larger systems that govern every aspect of our lives, from the benign to the essential. The number of IoT devices grew from 500 million in 2003 to 8 billion in 2017 and is expected to grow to 50 billion in 2020.

These disruptive forces have a tangible influence on citizens' rights such as statutory rights—due process, equal representation before the law, the right to appeal, and trial by jury—and constitutional rights like freedom of expression, voting, and non-discrimination. Thus, it has never been more imperative to have an open discussion about the proliferation of technology in our lives and how it will affect our privacy rights and our security on both personal and national levels. It is also imperative for technologists, researchers, and innovators to take heed of the policy debate and meaningfully contribute to the development of these policies.

It is true that Facebook is currently being investigated by the Federal Trade Commission (FTC) for violating a 2011 consent decree. However, it is clear that the processes exposed by the current Cambridge Analytica controversy reflect a severe challenge to US privacy law, which is sorely deficient. In this article, we review how Cambridge Analytica was able to leverage its alliance with Facebook to access users' personal data, lay out principles for a comprehensive data privacy policy, and examine what's currently proposed on Capitol Hill and at state levels to address privacy concerns.

CAMBRIDGE ANALYTICA

In 2013, researchers at the University of Cambridge's Psychometrics Centre analyzed the results of volunteers who took a personality test on Facebook to evaluate their "OCEAN" psychological profile (openness, conscientiousness, extraversion, agreeableness, and neuroticism) and correlated it with their Facebook activity (likes and shares).[3] This research drew in 350,000 US participants and established a clear relationship between Facebook activity (and other online indicators) and this five-factor personality profile. This work demonstrated that the OCEAN profile for any individual could be deduced reasonably accurately by looking at these metrics and without using a formal psychographic instrument. There is no indication, however, that this research exposed participating Facebook users or their friends to any specific privacy abuse. There are indications that the university refused to share data (either individual or the resulting criteria) with what would become Cambridge Analytica.

Now that it was clear that such an analysis could be undertaken, a second research project was reportedly initiated by Global Science Research (GSR)—in cooperation with Cambridge Analytica— to identify the parameters needed to develop the OCEAN profiles using a personality quiz on Amazon's Mechanical Turk platform and Qualtrics, a survey platform. The quiz required users to grant GSR access to their Facebook profile, which granted access to users' friends' data through the Facebook Open API until May 2015. This is how Cambridge Analytica was able to access the Facebook data under scrutiny. Note that keeping the specific individual data was not necessary to accomplish the primary research goal, which was to establish a methodology for psychographic profiling of individuals based on social media and other indicators.

Cambridge Analytica realized they could integrate this information with a range of data from social media platforms, browsers, online purchases, voting results, and more to build "5,000+ data points on 230 million US adults." By adding OCEAN analysis to the other private and public data acquired, Cambridge Analytica developed the ability to "micro-target" individual consumers or voters with messages most likely to influence their behavior.[4] The OCEAN analysis was paired with a large number of targeted messages in "Project Alamo," which was employed for the election campaign of President Trump.[5] Some of these messages were created for the Trump campaign, and some simply leveraged "news" available on the Internet (which might have included content funded through the Russian campaign to disrupt the US elections). As described by Cambridge Analytica's CEO, the key was to identify those who might be enticed to vote for their client or be discouraged to vote for their opponent.[6] Every vote added or disrupted (in the intended way) tips the election results. This parallels analysis from the US 2010 elections.

It has never been more imperative to have an open discussion about the proliferation of technology in our lives and how it will affect our privacy rights and our security.

Note that not having a Facebook account did not provide protection—the litany of available data sources is not limited to Facebook, and the analysis can easily apply to other points of personal preference. In addition, every website with the Facebook logo is linked to Facebook, allowing for tracking of non-members as well as members who might not have opted in for the service. There are many similar sources of online tracking—for instance, web beacons—most of which are tied to "cookies" that can be used across websites, and access can be sold to interested buyers. Also, by combining real news with misinformation or unconstrained Internet content, target voters will find reinforcing messages on many sites without realizing they are some of the few people in the world getting those messages, nor are they given any warning that these are political campaign messages.

With real-time monitoring of ad responses on targeted individuals, including real-time substitution to find "click bait" that worked, the ad campaign was able to both maximize its impact and detect trends not visible at the macro scale. Tipping the scale in a few states—with as few as 100,000 voters—using individualized, high-impact messages is sufficient to impact election results. This might not be the only reason for the specific 2016 US election outcome, but there is every indication that it was a useful if not a critical contribution.[7,8]

The idea that psychographic analysis can have a significant impact on behavior has been questioned. However, a recent paper by Stanford professor Michal Kosinski (who was part of the 2013 Cambridge University research team) and colleagues confirms that it can have a significant impact with a sample base of 3.5 million users.[9]

With a broad base of personal information readily available, micro-targeting of individuals can be easily deployed. Targeted messaging can be applied to affect their behavior, bypassing existing regulations on disclosure, informed consent, or even foreign intervention. The cost of applying these methods are meager. These factors suggest that changes in policies at both corporate and legislative levels are needed to ensure that consumers and voters' personal data is protected, that they are notified of the affiliation of those seeking to influence them, and that they have the best opportunity to participate as informed citizens and consumers.

THE CORE PRINCIPLES OF PRIVACY AND DATA PROTECTION

In our view, any privacy and data protection legislation should include the following principles, based on the forthcoming "Personal Privacy, Awareness and Control" position statement from IEEE-USA.[10]

Public transparency:

- The public must be able to learn the types of data being collected by any website or other electronic means, what data is retained, how it is used, and what is shared with third parties (directly or indirectly). The same information must be available from those third parties.
- All data collection mechanisms must be disclosed to users, including web beacons or other mechanisms for tracking user activity or data. This information must be sufficient for users to be able to identify and pursue disclosure and controls related to these data collectors.
- Each website and application must disclose any ongoing content placed on the user's device, as well as the uses of that content.

Disclosure for users:

- For each website and application, users must be able to obtain complete disclosure of the information that is retained about them by the site or application or by any third parties accessing that information, directly or indirectly.

Control:

- User "do not track" requests must be respected, blocking disclosure by third-party cookies and retention of non-relationship-critical data between sessions. Users must explicitly opt-in to each specific data component to be retained in this situation. This requirement extends to all "partner" third-party sites, cloud services, and collection devices.
- Users must easily be able to delete personally identifiable data from any site, cloud service, or collection device.
- Users must easily be able to identify, terminate, delete, and uninstall any content or applications placed on their devices or cloud service.
- Disputes related to the purging of user data or applications must not default to licenses and arbitration processes that restrict legal response options.
- Consent by users for a website to collect data about themselves must not be interpreted to extend to information about their "friends" or "contacts."
- Minors must be protected by a legally mandated age of consent to release their private information.

Notification:

- Users must be directly and promptly informed of the loss or misuse of their private information by any organization collecting or storing that information.
- Where and when possible, users shall have the right to know the source of violations and the responsible parties who violate their privacy.
- Paid advertising and content

must be accompanied by clear information notifying the recipient that this is paid content, with a clear link to the source of the material and the intended beneficiary of the desired consumer action.

- For online content, metadata should lead to the sponsoring site(s), allowing the user to understand and pursue the transparency, disclosure, and control actions indicated above.

CURRENT PROPOSED LEGISLATION

At the federal level, following the grueling and lengthy hearings before the House Judiciary and Senate Judiciary and Commerce Committees where Mark Zuckerberg was asked to testify on Facebook's privacy and data policy, a few senators put forward bills attempting to govern public data privacy. The most overarching bill comes from the offices of Senators Richard Blumenthal (D-CT) and Ed Markey (D-MA). The bill, titled the CONSENT Act (S.2639) or "Customer Online Notification for Stopping Edge-Provider Network Transgressions" (www.congress.gov/bill/115th-congress/senate-bill/2639/text?q=%7B%22search%22%3A%5B%22privacy%22%5D%7D&r=15), requires the FTC to establish privacy protections for customers of online edge providers.

The bill will require explicit opt-in consent from users of Facebook and other online platforms before these online platforms use, share, or sell any of their users' PII, as well as explicit notification any time data is gathered, shared, or sold to a third party, in addition to adding new reporting requirements in case of a data breach involving sensitive customer proprietary information. The bill describes violations of this act similar to unfair or deceptive acts prescribed under section 18(a)(1)(B) of the Federal Trade Commission Act (15 U.S.C. 57a(a)(1)(B)), thus giving the FTC jurisdiction to prosecute violators.

The Social Media Privacy Protection and Consumer Rights Act of 2018 (S.2728; www.congress.gov/bill/115th-congress/senate-bill/2728/text?q=%7B%22search%22%3A%5B%22privacy%22%5D%7D&r=2), introduced by Senator Amy Klobuchar (D-MN), draws similar constraints to the CONSENT Act regarding disclosure of privacy policy and obtaining initial consent and privacy preferences, but adds restrictions on modifications to privacy terms, provisions regarding withdrawal of consent, and procedures when a violation of privacy has occurred (for example, notification, data erasure, and ceasing to collect any further data).

California is taking the lead in the US by advancing a privacy bill to the State Legislature that would grant its citizens data privacy rights.[11] The bill adds limits to selling data on users younger than 16 years of age and prevents businesses from denying service to users should they choose to exercise their rights under the bill.

The privacy debate on Capitol Hill might have lost some momentum from when it started in April after the Facebook/Cambridge Analytica data misuse was revealed. At present, Congress might be more occupied with passing authorization and appropriation bills for 2019. Yet the debate is far from settled, and it remains to be seen if the Blumenthal-Markey or the Klobuchar bills advance to the floor for a vote and if the California legislative measure will set a precedent for the rest of the states, which could follow suit.

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Security-Informed Safety: Supporting Stakeholders with Codes of Practice

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Codes of practice provide principles and guidance on how organizations can incorporate security considerations into their safety engineering lifecycle and become more security minded.

Safety engineering has a good, though not unblemished, record of providing high technology that is safe and effective. However, the increasing prevalence of risk from cyber threats and the well-documented trend toward more complex and interconnected systems mean that change is needed if that record is to continue or improve. We participate in a program that aims to transform the way safety engineers think, in order to make "security mindedness" a common practice—to consider the impact their work might have on security as well as the impact security may have on their work. Our goal is to make safety engineers more aware of security and to give them the processes, procedures, and knowledge to successfully apply it to their efforts.

Toward that end, we developed two codes of practice (CoPs) for the rail and automotive sectors, sponsored by government with support from industry stakeholders. We built on our previous work on security-informed safety, which was summarized in a previous *Computer* article.[1] The two CoPs are intended to complement and standardize current industry initiatives and to create a process for cooperation between security and safety engineers. They are primarily aimed at people with a safety background who need to know how security issues impact their existing safety practice, but in response to comments from our industry stakeholder group we have

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also provided a route through the documents for those with a security background.

SCOPE OF THE CODES OF PRACTICE

Each CoP applies to the entire rail or automotive transportation ecosystem and is intended to help suppliers, operators, and maintainers of systems used in a connected transportation system ensure that security-related risks in their products, services, or activities do not pose unacceptable risks to safety. Security concerns that are not directly safety-related, such as confidentiality, privacy, and theft, as well as financial and reputational risks fall outside the CoPs' scope.

The CoPs apply to risks that can affect a single system or a few systems. They also give recommendations for managing systemic risks that might appear small but become significant when interdependencies are considered and the failure of a single or a few entities could result in widespread failure. Another important aspect of the CoPs is the recognition that every organization within the transportation ecosystem should be a "good citizen" with regard to cybersecurity to minimize the safety risks to users of transportation systems and society as a whole.

DEVELOPING THE CODES OF PRACTICE

There is plenty of advice and guidance available on safety and security, but it can sometimes seem rather ad hoc. To justify the structure and contents of the CoPs and to ensure complete coverage of the system lifecycle, we adopted a more systematic approach for each CoP that would

- develop a generic set of principles that are applicable to security-informed safety from analysis of existing related principles, consideration of the objectives of security-informed safety, and experience with developing security-informed safety assessments;
- adapt these generic principles to the rail and automotive industries by providing appropriate annotations and comments; and
- provide a set of supporting appendices that include more detail and guidance about the application of the CoPs.

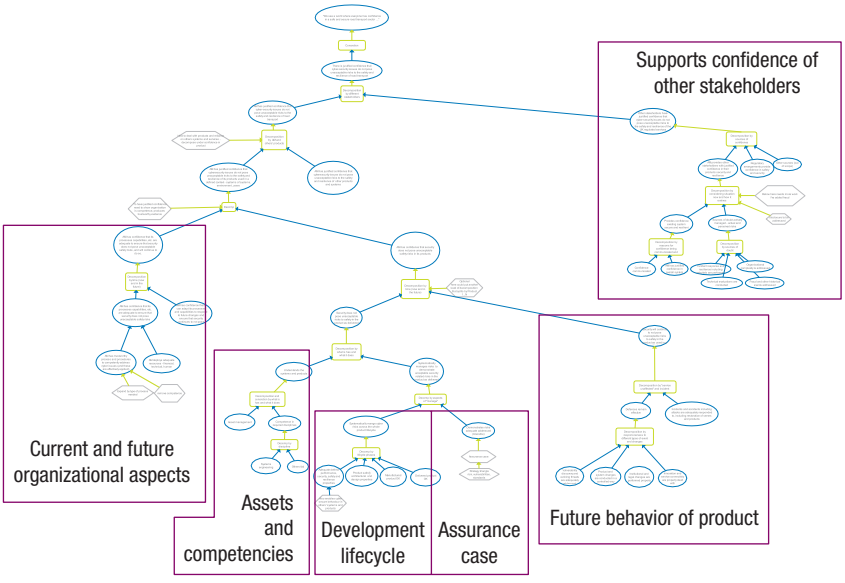

Figure 1. Claims-Argument-Evidence (CAE) structure for the codes of practice (CoPs).

We undertook initial development of the CoPs using a combination of top-down and bottom up approaches.

Top-down view

To develop and justify the generic principles for each CoP, we constructed a Claims-Argument-Evidence (CAE) case showing how the principles support a high-level vision for industry.

The top-down approach started from an overall vision for the transportation sector, for example: "We see a world where everyone has confidence in a safe and secure rail transportation sector." From this, we derived a top-level claim: "There is justified confidence that cybersecurity issues do not pose unacceptable risks to the safety and resilience of rail transportation." Then, using the CAE approach to assurance, we developed a network of linked subclaims supported by a set of principles. We used these to derive the CoP recommendations.

The complete CAE structure we developed is shown in Figure 1, which identifies the main sets of principles. These include claims about

- current and future organizational aspects,
- assets and competencies,
- the development lifecycle,
- the assurance case,
- future behavior of the product, and
- supporting confidence of other stakeholders.

TABLE 1. CoP organization and contents.

Section	Indicative contents
1. Security policy, organization, and culture	The impact of security considerations on existing safety policy and organizational culture
2. Security-informed development process	Security requirements for each phase of the system lifecycle
3. Maintaining effective defenses	Ensuring that security is maintained during operation
4. Incident management	Managing security incidents
5. Secure and safe design	Building security into the design of the system
6. Contributing to a safe and secure world	Cooperation and collaboration with other organizations to improve the security of the transportation ecosystem

TABLE 2. CoP appendices.

Appendix	Indicative contents
A. Derivation of principles	Explains how the high-level set of principles that inform the CoP were derived
B. Risk assessment	Describes approaches to combining safety and security risk assessment
C. Assurance and safety cases	Provides an introduction to assurance and safety cases
D. System composition	Discusses the challenges posed by systems of systems
E. Network security	Factors to consider in order to determine whether a network is secure—the distinction between open and closed networks
F. Secure coding	Provides an overview of standards and guidance for secure software development

Bottom-up view

The bottom-up approach started from existing sets of security- and safety-focused principles and guidance produced for a number of safety-related sectors, including the following:

- UK government, *The Key Principles of Cyber Security for Connected and Automated Vehicles*[2]
- EU Agency for Network and Information Security: *Cyber Security and Resilience of Smart Cars: Good Practices and Recommendations*[3]
- US National Highway Traffic Safety Administration: *Cybersecurity for Modern Vehicles*[4]
- UK National Cyber Security Centre: EU Network and Information Security (NIS) Directive guidance[5]
- UK Office for Nuclear Regulation: *Security Assessment Principles for the Civil Nuclear Industry*[6]

Although none of these documents addressed the exact scope of the project, they were all useful resources.

We examined overlaps between these various sets of principles and extracted common themes. We then compared these common themes with the initial set of recommendations derived from our top-down approach to ensure that there was adequate coverage of the important points.

Using this bottom-up approach, we identified a set of categories and mapped the various sets of principles onto these categories. Our analysis identified three broad categories of principles:

- organizational security,
- product or project lifecycle, and
- design principles (covering architecture through component design).

CODES OF PRACTICE ORGANIZATION AND CONTENTS

Based on our top-down and bottom-up analyses, we identified six broad topics that formed the sections of each CoP, as shown in Table 1.

Each CoP also contains a number of appendices that provide more detailed guidance on specific topics to help organizations implement the recommendations, as summarized in Table 2.

In line with modern regulatory approaches, the recommendations in the CoPs are framed as outcome-based measures, accompanied by notes about the characteristics that adequate implementations of these measures would be expected to have.

EXAMPLE: CONTRIBUTING TO A SAFE AND SECURE WORLD

Here we illustrate the CoPs' general style and content. Each section of the CoP begins with some introductory text that discusses the impact of security considerations on this particular aspect of safety practice. For example, the introduction to Section 6, "Contributing to a safe and secure world" (see Figure 2), contrasts the open culture of safety toward learning from accidents and near-misses with the need to share information about security vulnerabilities in a responsible and controlled way. It also explains that ensuring the ecosystem's security is a shared responsibility and introduces the concept of "herd immunity."

Following the introduction, the recommendations for that section are grouped into a series of topic areas. Each topic has numerous clauses that are expressed as outcome-based measures (what should be done, not how it is to be done), accompanied by explanatory notes and pointers to relevant guidance and standards where appropriate. Figure 3 shows the recommendations for Section 6.

Section 6: Contributing to a safe and secure world

In safety industries, lessons learned are typically shared to push best practice forward. The safety of systems is often communicated to end users and society at large via compliance with regulations, certification to standards, or specific testing schemes. Accident and near-miss investigations provide a formalized route for learning from experience, especially in the regulated high-hazard industries.

In contrast, in a security context, information that might help adversaries to optimize their behavior needs to be protected. This includes information on vulnerabilities that are in the process of being patched, details of the organization's threat intelligence, or details of both successful and unsuccessful attacks.

It is worth noting that an organization's assets could be used to compromise the assets of another, and the resilience of the transportation system as a whole can be improved if all assets involved are hardened against attack—so-called herd immunity—and information on security vulnerabilities and failure modes is shared to enable appropriate design decisions to be made. While the safety-focused organization will be attuned to the need to monitor, respond, and learn from and share experience, security will bring new definitions of what constitutes an event worth reporting, changes to how and to whom this information is reported, and the protocols for reporting and escalating externally. This is particularly relevant in the context of systemic failure, where hazardous situations can be caused in a class of systems due to a shared common vulnerability.

Figure 2. Introduction to CoP Section 6.

BALANCING SECURITY BY DESIGN AND SECURE OPERATION

Building systems that are both safe and secure requires a defense-in-depth approach. Ideally, systems should be secure by design. Failing that, they should be operated in a secure environment. Moreover, procedures should be in place to deal with the possibility of the secure environment being compromised.

The CoPs make a distinction between building systems that are secure and safe by design and ensuring that systems remain secure and safe during operation. Many legacy systems were designed to operate safely on a closed network but are vulnerable to attack if they are connected to an open network. Such systems were built to be safe but are not necessarily secure because they assume a benign environment. As it might not be possible to patch vulnerabilities in a legacy system, the security risk must be managed. However, new systems should be designed to be secure and safe by default, and to withstand an attack from an adversary that has gained access to a protected network zone. Also, mechanisms should be in place to detect the presence of adversaries in the protected network zone and limit or quarantine their access to the rest of the network.

The CoPs contain advice and guidance on all of these topics, specifically

- security-informed development process,
- secure and safe design,
- maintaining effective defenses, and
- incident management.

The CoPs are not intended to replace existing safety and security standards and guidance, but rather to provide principles and guidance on how organizations can incorporate security considerations into their safety engineering lifecycle and become more security minded. One of our goals in writing the CoPs was to keep the core guidance to about 20–30 pages, which we have achieved. The CoPs are structured as a set of high-level recommendations, with notes and references to relevant standards and appendices that provide more detail on specific technical topics.

Our principled approach to creating a generic CoP that can be adapted to particular sectors such as rail and automotive has been successful. Relatively few clauses in the CoP exclusively relate to rail or automotive transportation—most of the advice and guidance is applicable to both sectors.

6.1 Managing risks

6.1.1 The organization should assess and manage risks to

a) the wider transportation system
b) society more generally

that might be derived from failure or compromise of its products or services.

NOTE 1: The approach will depend on the safety-related nature of the product or service and the regulatory regime that applies.

NOTE 2: Examples of risk to society generally might include the widespread failure of the organization's products and services, leading to a reduction in transportation capacity with a consequential impact on many other activities.

6.2 Compatibility and interoperability

6.2.1 The organization's products and services should make use of industry-adopted standards for communication and security, where they can be shown to support adequate levels of safety and security.

6.3 Information sharing

6.3.1 Organizations should enable customers to assess the security of their products and services by making sufficient design and assurance information available.

NOTE: To protect intellectual property, confidential information such as detailed design documentation can be made available under a nondisclosure agreement.

6.3.2 The organization should be able to provide third parties with assurance or certification that the organization's processes relevant to the production of a safe product or service are secure.

6.3.3 The organization should collaborate with relevant organizations to obtain knowledge and understanding of current and relevant threats.

6.3.4 If the organization becomes aware of vulnerabilities that affect or might affect the products or services of another organization, it should responsibly disclose such vulnerabilities to those organizations.

NOTE: Vulnerabilities might be identified through post-incident analysis (see Section 4.5), or reported by third parties.

6.3.5 The organization should support other organizations in the ecosystem to understand and manage security risks arising from the use or abuse of its services or products.

NOTE: Relevant organizations might include governmental organizations (including security agencies), industry umbrella groups, and other industry actors.

6.4 Collaboration

6.4.1 The organization should collaborate with relevant organizations to share, develop, and foster the adoption of good engineering practices to mitigate current and relevant threats.

NOTE: Relevant organizations might include governmental organizations (including security agencies), industry umbrella groups, and other industry actors.

6.4.2 The organization should define an approach for adopting open design practices and deciding when and how to share designs and source code.

6.5 International issues

6.5.1 Organizations should consider the implications of working with organizations from other countries throughout their supply chain. Some countries may harbor malicious intent toward the UK.

NOTE: Further guidance on supply-chain risk is available from the Centre for the Protection of National Infrastructure (https://www.cpni.gov.uk/supply-chain) and the National Cyber Security Centre (https://www.ncsc.gov.uk/guidance/supply-chain-security).

Figure 3. Recommendations to CoP Section 6.

We currently have mature drafts of both CoPs that are being reviewed by industry stakeholders before going out for wider distribution; the Publicly Available Specification (PAS) is available from the British Standards Institution (BSI) as PAS 11281. To build consensus around the CoPs, we plan to organize a series of workshops with representative stakeholders to explore the CoPs' application to their situation. We propose that all safety justifications should consider security, and an important next step is to show how following the CoPs can produce a security-informed safety case.

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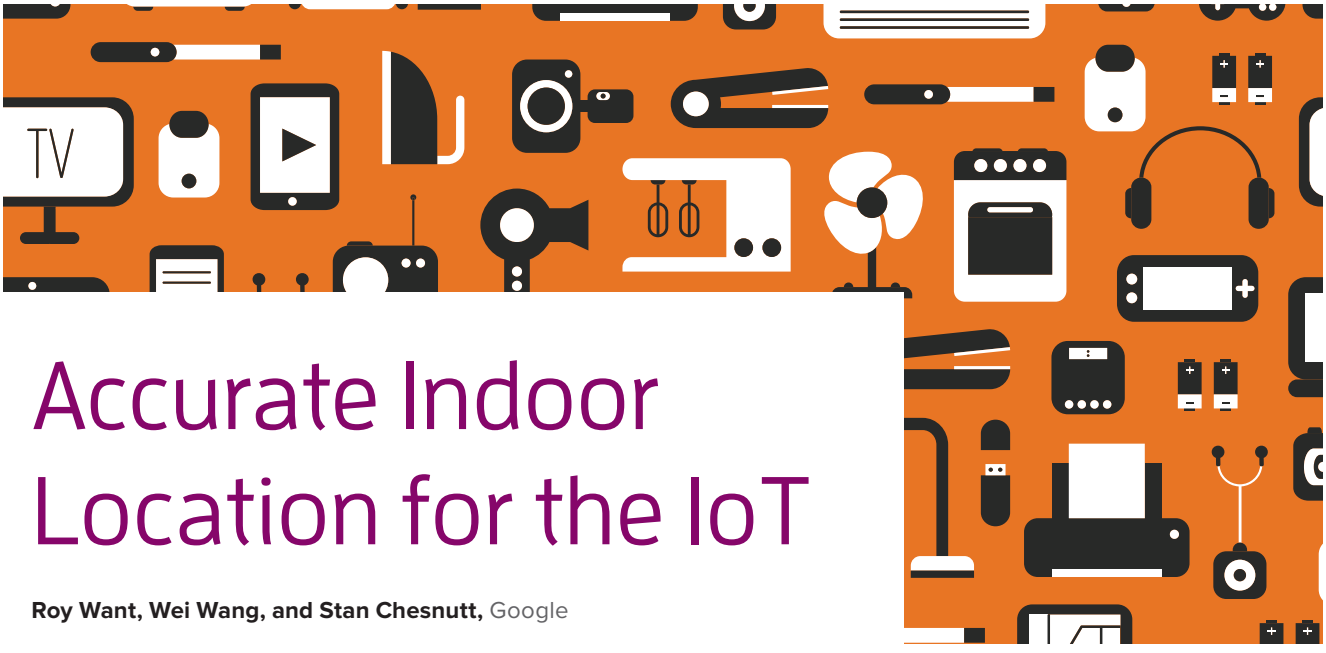

Accurate Indoor Location for the IoT

Roy Want, Wei Wang, and Stan Chesnutt, Google

The combination of IoT and accurate location-finding technologies will enable a wide range of novel context-aware services to automate tasks and support everyday work practice.

A defining characteristic of the Internet of Things (IoT) is that devices are both networked and embedded in the environment. Unlike traditional networked server technology that has very little connection with the environment, IoT devices are designed and positioned so that they can respond to and influence their surroundings. For example, if a user accesses a web server from an office in California, it makes very little difference whether the service is located in the next building or situated in Europe. However, if a user accesses an IoT device that is responsible for measuring the temperature of a room, the sensor and device need to be located in that specific room.

As a result, IoT design is a unique departure from infrastructural networking that tries to abstract away the network topology; instead, the topology and position of IoT nodes are assets in performing the networking task.

IoT devices often contain sensors and actuators. Consumer products for IoT sensors include light sensors, microphones, cameras, security switches, motion detectors, thermostats, barometers, moisture sensors, and when extended to industry, a wide variety of exotic sensors. Actuator outputs include lamps, valves (water sprinklers), speakers, and a variety of displays—again, industry has many additional needs for bespoke actuators. The interrelationship of the position and function of each of these devices allows us to design systems that are often called "smart homes" or "smart buildings."

An additional consideration of spatially arranged infrastructure is that mobile wireless components can move through it. In a smart home, people will be present and the infrastructure is intended to make their lives easier and more comfortable. Devices such as lights, HVAC, and security systems can be turned on or off by the presence and detection of people entering or leaving an area. This is not only convenient, but also addresses human forgetfulness and has cost-saving implications because it reduces energy consumption.

In the modern smart home, voice-driven assistants have become popular (such as Amazon Echo and Google Assistant) and allow devices in smart homes to be activated by casual voice commands. Typically, human speech is often tersely phrased with the assumption that the context is understood. This is challenging for a computer, which doesn't have the shared context to respond

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to these commands. One of the biggest qualifiers of context is a user's position. For example, an ambiguous command such as "turn on this lamp" can be immediately qualified if the system knows the relative position of the user and all the nearby lamps.

Although it might be hard to determine the location of a person, it is now possible to accurately calculate the position of a mobile device using Wi-Fi radios (see www.ieee802.org/11) with positioning support. Since the early Wi-Fi (802.11b) products appeared in 1999, Received Signal Strength Indication (RSSI) has been used to determine the approximate position of a mobile device relative to surrounding access points installed at known positions.[1] More recently, Bluetooth low-energy beacons have been used in a similar way, but at higher density due to their small size and low cost. However, due to multipath fading, the RSSI fall-off from the antenna does not follow a uniform inverse square law and is distorted by the building materials that it travels through. As a result, the position accuracy for Wi-Fi can often have large errors of 10 to 20 meters. Improvements have been made by measuring the RSSI fingerprints for all detectable access points at each square meter of a building, but this requires considerable investment in surveys, which are labor intensive and have to be regularly updated.

A more accurate approach was needed that could localize a device to about 1 square meter (the area occupied by a person), but only required the knowledge of Wi-Fi access point positions.

THE IMPORTANCE OF A STANDARD

In December 2016, the IEEE 802.11 working group ratified amendment 802.11-REVmc[2] for the Wi-Fi standard, which included a new ranging capability based on time of flight (ToF) of Wi-Fi packets. As these packets are transmitted as RF signals that travel at the speed of light *c*, the distance can be calculated by knowing the ToF of a packet from a mobile to an access point and multiplying by the speed *c*. Knowing the distance or range to three or more access points (and using a process called multilateration), the mobile's position can be calculated (see Figure 1).

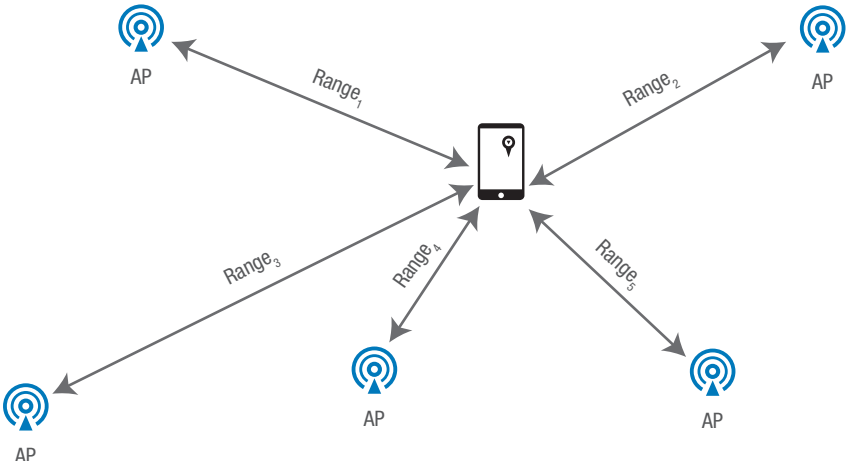

Figure 1. Multilateration, the process of converting ranges to a position. AP: access point.

In recent times, there have been other radio ranging standards (for example, ultrawideband [UWB], which was standardized in IEEE 802.15.4a[3]), but none have had much impact on the mobile industry. Wi-Fi is different because of its wide-scale use in mobile phones, laptops, and tablets throughout the world. And most importantly, Wi-Fi access points' infrastructure has grown as a grassroots effort and is deployed ubiquitously, including in many public spaces.

The spread of Wi-Fi has been enhanced because of three value propositions:

- it has a practical range of about 25m, and as a result the density and related cost of access points to cover a work area are not great;
- its power consumption is low enough that it can be embedded into small mobile devices with acceptable impact on battery life (for smartphones and tablets); and
- the data rate of Wi-Fi products has remained competitive and has typically had a x10 advantage over cellular data, which often has a data limit and results in additional cost if exceeded.

Wi-Fi has an additional characteristic in that it has already been improved several times to meet growing user demands. There is a natural upgrade cycle for Wi-Fi as radio technology improves and as users crave higher data rates to support video and faster downloads. These upgrades also serve as a vector for new features (such as ranging) that can be introduced in each upgrade cycle.

In short, Wi-Fi 802.11-REVmc is ideally suited as a standard to disseminate a new positioning technology with the potential for a wide reach and the opportunity for mobile application developers to build on its novel capabilities.

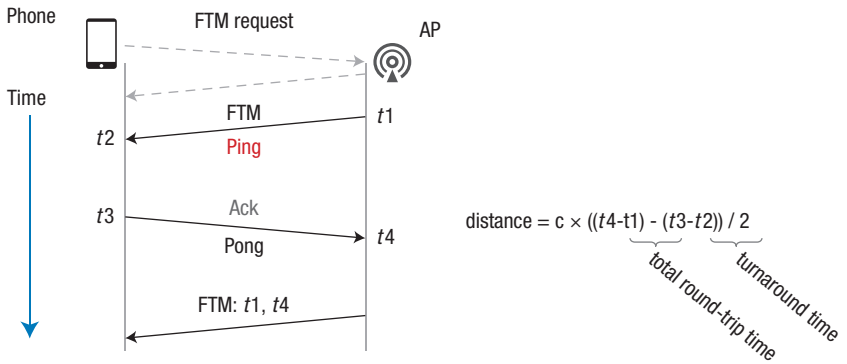

Figure 2. The 802.11mc Fine Timing Measurement (FTM) Protocol.

IEEE 802.11-REVMC AND WI-FI ROUND-TRIP TIME

The core of the 802.11-REVmc protocol is built around a new packet type called a Fine Timing Measurement (FTM) frame. The recipient responds to an FTM with an acknowledgement packet, and the transmission and reception times of each are recorded. It's basically a ping-pong protocol that calculates ToF by measuring the time it takes for a packet to be sent from an access point to a mobile and then back again. This is called the round-trip time (RTT), so the protocol is sometimes referred to as Wi-Fi RTT.

For a mobile device to measure the ToF, the precise times of the packet leaving the access point ($t1$) and arriving at the mobile receiver ($t2$) must be known. Further, the precise times the mobile device transmits the response ($t3$) and the time it is received back at the access point ($t4$) must also be recorded. From the mobile's perspective, it measures only $t2$ and $t3$ as they occur locally at its radio. However, $t1$ and $t4$ are measured at the access point, so for the mobile to calculate the RTT, the access point needs to send $t1$ and $t4$ as an additional message to the mobile (see Figure 2), which is piggybacked on the next FTM packet.

The phone can now calculate the RTT based on the total time $t4 - t1$, subtracting $t3 - t2$ to account for the turnaround time of the acknowledgement packet.

$$RTT = (t4 - t1) - (t3 - t2)$$

The desired range is determined by multiplying by the speed of light c and dividing by 2, as we are only interested in the distance from mobile to access point and not the round-trip distance.

$$range = c \times RTT / 2$$

Some general assumptions are made that the clocks are running at about the same rate on the two devices, and with a modern crystal oscillator with an accuracy of 40 parts per million, this is reasonable. Note that the clocks of each device don't need to be synchronized as the $(t4 - t1) - (t3 - t2)$ terms provide time differences for each separate clock at the beginning and ending of each exchange, and therefore do not require an absolute time reference. Given the typical clock stability and an 80 MHz bandwidth in the 5 GHz Wi-Fi band, the expected accuracy of this protocol is expected to be ~1m, which meets the design goals and considerably outperforms approaches based on RSSI.

INCREASED LOCATION ACCURACY ENABLES NOVEL APPLICATIONS

Important questions for the design of any positioning system are "What is the position system going to be used for?" and "What target accuracy is needed?" If a system has an accuracy of 10m and is improved to 9m or even 8m, does it make the system more useful? Perhaps not that much. However, if you were to improve it to 1m, it would cross a significant human threshold because a person typically occupies about 1 square meter of standing space. It opens up the possibility to place a person next to another person, product, or thing.

For Wi-Fi RTT, 1 to 2m is just less than the width of most corridors or aisles found in a building. This resolution actually enables in-building navigation, for example, directing a person to a product in a store or an office worker to an unfamiliar conference room. Errors two to three times this size would cause the indoor navigation system to place you in the wrong aisle, resulting in a confusing user experience. In the same way that GPS is accurate enough (~5m) to place a car on the correct road, in-building navigation is enabled by a 1 to 2m Wi-Fi location system. In combination with indoor maps and a routing system calculating the shortest path, Wi-Fi RTT can show your progress along a route and provide corrections by rerouting when you deviate from the path.

In the IoT world, ~1 meter accuracy can automatically determine the location of devices such as lights and thermostats, which might not have their exact position recorded. Positioning to ~1m can automate the documentation for an installation process, reducing contractor time and removing transcription errors that inevitably occur in hectic construction environments. Further, it can automatically keep records up to date as devices are replaced and during remodeling.

In daily work practices, users carrying mobile devices with Wi-Fi RTT can be located in a smart home (using an application with permission from the owner) and automate the operation of heating, lighting, door locks, and security systems. The modern smartphone is a multipurpose device, and owners typically carry the device with them most of the time. As home

monitoring and control capabilities grow via smartphone apps, we expect that users will make use of these apps in their everyday lives.

There are further advantages for accurate location in peer-to-peer interactions. When two devices are next to each other, there is the opportunity to share information. For example, if a user wishes to share a photo, it might be done with a simple flick gesture on a screen. A phone that can detect the proximity of nearby devices can limit the scope of gesture-based sharing to the closest device. You can imagine many other forms of digital peer-to-peer transfers that are made possible by automatically and accurately detecting close proximity, which includes ticketing and payments.

LOCATION DATA AND PRIVACY

We have already seen that accurate location can bring many advantages to daily work practice and social interactions. However, there are important privacy implications to consider, and great care needs to be taken when implementing and enabling these services for users.

Mobile devices that can repeatedly link a user's identity to the device's location create a location "trail," which could result from location data being stored persistently on the device or uploaded to a server. With nefarious access to this information over time, it's straightforward to determine the habitual whereabouts of the user, which could be used to tip off thieves or others with malicious intent.

Protecting the user's privacy starts with an agreement with the user. First, the software must request explicit permission to establish the user's location and to store that information. Second, persistent location information must be carefully protected after being uploaded to a central server (for example, protection against reuse in unexpected ways and against observation by a rogue employee). This need for protection also applies to raw ranging data, not just position, as it can also be converted to user location by a nefarious party.

Furthermore, an IoT device might have capabilities that can threaten user privacy when coupled with location data. For example, a security camera that uploads video data could also add identity and location information.

The European Union's General Protection Data Regulation (GDPR) establishes clear standards for data retention, storage, and use. These guidelines should be treated as a starting point for data stewardship.

THE FUTURE OF LOCATION TECHNOLOGIES

Going forward, we expect 802.11-REVmc to be adopted by a wide variety of client devices and access points, which will result in many novel location-based applications that can make use of ~1m indoor accuracy. The designers of the first Wi-Fi RTT protocol had many additional features that they wanted to include, but they had to be deferred due to the timing of the first release.

A more extensive set of location protocol features are currently being undertaken by the follow-up task group 802.11az (Next Generation Positioning), whose primary goals are to enable greater scalability and provide for secure operation.

The 802.11az task group is developing a protocol that takes advantage of the new high-efficiency (HE) data standard being developed in parallel in Task Group 802.11ax with four times the data throughput of existing 802.11ac-based systems. In addition to higher-density coding, the radio supports multi-user uplink MIMO (multiple input, multiple output), allowing more spatial parallelism in data streams than before and resulting in more efficient use of the communication channel. Location techniques can take advantage of this mechanism by ranging between an access point and several stations simultaneously, thus supporting a larger number of potential clients.

An additional technique that supports even larger populations of clients is called passive ranging. This mechanism is characterized by mobile devices that only need to listen to the transmissions made by other stations and never need to transmit themselves. The result is that the channel capacity is not affected by the number of users trying to measure their position—furthermore, privacy is guaranteed as a mobile never needs to announce its presence. In that sense it's similar to the operation of GPS, although it differs in the geometric calculation needed to determine a position.

An IoT device might have capabilities that can threaten user privacy when coupled with location data.

In this technique, special types of access points called anchor stations range to nearby access points. If a mobile device listens to the protocol exchanges between anchor stations and access points, it can use the reported timestamps to figure out the time difference of arrival of two packets at its receiver, as if they were sent simultaneously from two known positions. This information allows a mobile to place its position on a hyperbolic curve. When repeated for multiple pairs of anchor stations and access points and at known positions, the mobile can calculate its position by determining the intersection point of these hyperbolic curves.

Authentication and security are

always important—even more so when wireless devices are involved, because it's often hard to determine the entity that a mobile device is communicating with. For example, when you are in an unfamiliar location such as a large airport, are you aware of the access point your smartphone is associated with? 802.11az sets out to address this problem and provides the following mechanisms.

- A mobile device can ensure it's ranging to a trusted infrastructure. In other words, a mobile device should be able to reject potentially false range or positioning information from a nearby rogue access point.
- If a mobile device A is ranging to nearby access points, it should not be possible for another nearby nefarious mobile device B to overhear and decode the ranging packets. Therefore, B should not be able to calculate the position of A.
- Infrastructure that determines the location of a mobile device (assuming a user has given it permission to use that information) should be able to validate that the mobile is not falsifying its position.

Lastly, 802.11az provides for operation in the 60 GHz band, which promises greater range accuracy to a few centimeters with the increased bandwidth. In practice, this means position accuracy could have 10 times the resolution of 802.11-REVmc, which will open up new categories of location-based applications.

Location technology is coming of age at a time when IoT technologies are proliferating. The combination of IoT and accurate location-finding technologies will enable a wide range of novel context-aware services to automate tasks and support everyday work practice. Over the next few years, we expect fine-grained location-based services to become more prevalent and rapidly become a standard feature used by smart infrastructure.

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IEEE COMPUTER SOCIETY ELECTION

CANDIDATES FOR COMPUTER SOCIETY OFFICERS AND BOARD OF GOVERNORS POSITIONS IN 2019

This section includes the position statements and biographies of the IEEE Computer Society's (CS's) candidates for president-elect, first vice president, second vice president, and Board of Governors positions. Election of officers to one-year terms and of Board of Governors members to three-year terms, each beginning 1 January 2019, will be by the vote of the membership as specified in the CS's bylaws. Within each category, candidates are listed in alphabetical order, and their biographies and statements are subject to word-count limits.

Only CS members without an email address in their member record, or those who have opted out of IEEE email communications, will receive a paper ballot package. Those who receive paper ballots should return them using the business reply envelope provided or send to IEEE Technical Activities, ATTN: SGA, 445 Hoes Lane, PO BOX 1331, Piscataway, NJ 08855-1331, USA. All other members will receive a broadcast email message with voting instructions to access their web ballot package information. Members (undergraduate students are not eligible to vote) in all regions can vote via the web at www.computer.org/election2018. For replacement ballots or to request a paper ballot, email ieee-computervote@ieee.org or call +1-732-562-3904.

The opinions expressed in the statements are those of the individual candidate and do not necessarily reflect CS positions or policies.

Ballots must be returned no later than 12:00 pm Eastern Time/16:00 UTC, on Monday, 24 September 2018. Results will be announced in *Computer*'s December issue.

COMPUTER SOCIETY'S 2018 ELECTION SLATE

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Leila De Floriani
William D. Gropp

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Second Vice President
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Jon Rosdahl

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Vladimir Getov
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Fabrizio Lombardi
Ramalatha Marimuthu
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Hausi A. Müller
San Murugesan
Kunio Uchiyama

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PRESIDENT-ELECT CANDIDATES

Leila De Floriani

POSITION STATEMENT. The IEEE Computer Society (CS) is the leading professional organization in computing with a mission to serve both researchers and practitioners. Its goals are to enable members to be at the cutting-edge of technical knowledge.

As the editor-in-chief of an IEEE Transactions, I have been at the forefront of implementing and successfully experimenting with highly innovative publication models based on strong interactions among CS activities. The adoption of synergistic modalities between conferences and journals is a compelling mandate that the CS must meet to enhance services and offerings, including introducing novel communication media for improved dissemination, such as author-produced short video summaries for journal issues and conference presentations. I will encourage and support publications and technical committees to work efficiently in this direction.

I have held positions in academic and research institutions in the US and Europe, and appreciate the different educational emphases on a worldwide basis, including Asia. This exposure has provided me with an understanding of the challenges and needs that different professional communities encounter for professional growth. I believe that I am in an excellent position to positively address these issues for all our members. Hence, one of my goals is to enhance our outreach to members in all regions through a multi-pronged initiative by which membership-based programs (such as student/professional chapters) will thrive, by sustaining focused initiatives (such as improving communication services for non-English speaking members) as well as global technical events, through, for example, the Distinguished Visitor program.

Another goal of my presidency is to enhance inclusiveness by increasing the diversity of our membership through outreach activities and the involvement of women and underrepresented groups, both as volunteers and in leadership positions in publications, conferences, and CS governance. I will also promote the enhancement of service recognition to our members as a further appreciative step for involvement in CS activities. In this respect, I am also very committed to the growth of students and young professionals. Activities

William D. Gropp

POSITION STATEMENT. To me, the Computer Society is first and foremost just that—a society and a community. The job of the leadership of the Computer Society is to build and improve on the framework of that society to ensure that it meets the needs of its members and our profession. This is a challenging time for the Computer Society, which needs to examine what it means to be a professional society in the 21st century and how to adapt in order to thrive in this changing environment.

As president, I have three main goals:

Connect. We need to work on connecting those in our profession to the communities of researchers and practitioners in our Society. We must make membership more attractive to students and to those in industry as well as academia. Like much of computer science, our membership can and must be more diverse. We are a very international field; our membership must reflect that as well. Our most powerful tools in this endeavor are our conferences, journals, and technical committees. We must build on these.

Communicate. Working together, we can increase communication and make that communication more effective and efficient. Within the Society, we can provide more ways, both unstructured (e.g., a virtual suggestion box) and structured (e.g., ad hoc committees) to communicate with our membership. We are also part of the largest professional organization; we can work with IEEE and our sister societies to share ideas and to leverage our resources. We also must work with external partners to better understand their needs. I use "we" here because, as your president, I must lead in setting up and enhancing the frameworks for communication, we must all do our part to improve communication.

Explore and Adapt. In an era of change, no one has all of the answers. A more robust way to thrive in the midst of change is to explore different options, encourage competition, and see which ones work best. And with success comes the need to adapt; I know first-hand that what works for a conference of 100 is inadequate for a conference of 12,000. I will work with the Board of Governors to develop ways to create pilot projects to help us learn what works best.

Leila De Floriani continued from previous page

and resources in support of new generations of scientists and engineers will be a priority in the operation of the CS.

In conclusion, if elected, I am committed to developing, enhancing, and promoting activities that support our members in their professional growth and foster inclusiveness and participation in the Society, while also addressing financial sustainability and providing value in terms of high-quality services, visibility, and research, all of which I pledge to uphold while serving as President.

BIOGRAPHY. Leila De Floriani is a professor at the University of Maryland, College Park. She has been a professor at the University of Genova (Italy) since 1990, where she developed the first undergraduate and graduate curricula in computer graphics in Italy, and served as director of the PhD program in computer science for eight years. During her career, she has also held positions at the University of Nebraska, Rensselaer Polytechnic Institute, and the Italian National Research Council.

De Floriani is a Fellow of IEEE and of the International Association for Pattern Recognition (IAPR), as well as a Pioneer of the Solid Modeling Association. She has been a member of the Board of Governors of the IEEE Computer Society since 2017. She is the chair of the 2018 Audit Committee and has served as a vice-chair of the Fellow Nomination Committee in 2017 and 2018. De Floriani is also an IEEE Computer Society Golden Core Member.

She is the editor-in-chief of the *IEEE Transactions on Visualization and Computer Graphics* (*TVCG*) and served as an associate editor for *IEEE TVCG* from 2004-2008. De Floriani is currently an associate editor of *ACM Transactions on Spatial Algorithms and Systems*, *GeoInformatica*, and *Graphical Models*. She has served on the program committees of over 150 leading international conferences, including several IEEE conferences, and has contributed to many conferences in a leadership capacity.

De Floriani has authored over 300 peer-reviewed scientific publications in data visualization, geospatial data representation and processing, computer graphics, geometric modeling, shape analysis and understanding, garnering several best paper awards and invitations as a keynote speaker. Her research has been funded by numerous national and international agencies, including the European Commission and the National Science Foundation.

For additional information, please visit: https://defloriani-ieee-cs-president-elect-candidate.umiacs.io/.

William D. Gropp continued from previous page

See my website http://wgropp.cs.illinois.edu/ieeepres.htm for some specific ideas and for more information about me. I look forward to serving you as president of the Computer Society.

BIOGRAPHY. William "Bill" Gropp is Director and Chief Scientist of the National Center for Supercomputing Applications and holds the Thomas M. Siebel Chair in the Department of Computer Science at the University of Illinois at Urbana-Champaign. He received his PhD in Computer Science from Stanford University in 1982. He was on the faculty of Computer Science at Yale from 1982-1990. From 1990-2007, he was a member of the Mathematics and Computer Science Division of Argonne National Laboratory, including serving as associate division director.

Gropp is a member of the Computer Society Board of Governors, serving on ad hoc committees for awards and growth. As chair of Technical Program (2009), Finance (2011), and as General Chair (2013) of the SC conference, which at over 12,000 attendees is the largest conference co-sponsored by the Computer Society, Gropp has experience leading volunteers (almost 600 for SC) and running financially successful technical conferences.

He has played a major role in the development of the MPI message-passing standard. He is co-author of MPICH, the most widely used implementation of MPI. He has written many books and papers on MPI including "Using MPI." He is also one of the designers of the PETSc parallel numerical library and has developed efficient and scalable parallel algorithms for the solution of linear and nonlinear equations. Dr. Gropp recently co-chaired the National Academy's Committee on Future Directions for NSF Advanced Computing Infrastructure to Support US Science.

Gropp is a Fellow of ACM, IEEE, and SIAM and received the Sidney Fernbach Award from the Computer Society in 2008, and the ACM/IEEE-CS Ken Kennedy Award "for highly influential contributions to the programmability of high-performance parallel and distributed computers, and extraordinary service to the profession" in 2016. Gropp is a member of the National Academy of Engineering.

See more at http://wgropp.cs.illinois.edu.

FIRST VICE PRESIDENT CANDIDATES

Dennis J. Frailey

POSITION STATEMENT. Why should someone join the Computer Society today? What is the value proposition? Our own technology has changed the answers to these questions as traditional forms of publication and communication are being transformed. No longer does the young student, faculty member, researcher, or working professional turn to printed journals as a primary source of knowledge. They look online and expect things to be free (or at least low in cost). Those who publish research results seek to publish quickly—a capability that our technology has made possible. Professionals, researchers, faculty members, and students have always been the vital components of Society membership, both as volunteers and as consumers of Society products and services. To remain viable, the Society must remain valuable to them. Our publications have gone electronic and our website is being enriched. Webinars and other educational programs are growing. But what else should we be doing?

Since my election as Second VP last year I've been delving into these questions. I've been a working professional for over 40 years and a publisher of technical papers, as well as a part-time college-level professor and speaker to many local groups through the DVP and other programs, so I'm familiar with these communities. We need to spend more time listening to them. Society leaders are mostly from a previous generation, and we don't always "get" what the younger members need. We should find ways to involve more of them in leadership positions within the Society. We need better alignment of Society activities that support local chapters, regional conferences, and other events that serve their interests. As a society VP, I've had the opportunity to bring Society resources to bear on these objectives, and I ask your support to let me continue the job.

BIOGRAPHY. Frailey is a retired Principal Fellow from Raytheon Corporation with over 50 years of professional service in IEEE, ACM and other computing technical societies. He's an IEEE Senior Member and ACM Fellow and has served in many capacities for both societies, notably the Board of Governors of the Computer Society (2011-16), 2nd VP and Secretary of the Computer Society (2018), and Vice

Forrest Shull

POSITION STATEMENT. The Computer Society is going through a transformative time. There are very different expectations about what membership should mean, what products and services consumers find valuable, and how users find and consume our content.

Our publications, for example, have experienced a profound transformation. Content now largely reaches consumers digitally, piecemeal through search engines, rather than through subscriptions. In various roles, including Editor in Chief of *IEEE Software*, I have helped manage this transition, spearheading the digital edition of a leading magazine and managing engaged volunteers who worked to take advantage of the new media. Today we are reaching audiences in new ways and with new types of content, for example, the interviews on timely topics through the SE Radio podcast.

To have a healthy Society, we need to be nimble enough to adapt our offerings to current expectations. We need to continue to be forward-thinking and able to innovate, but also be clear-eyed about which of our offerings are finding an audience and adapt as necessary. I have helped develop review processes that today give us a better baseline for understanding how well our current offerings meet the needs of the community, and for making strategic decisions informed by data. But there is much more to be done. Above all, we need to do a better job of connecting our members, and finding energized individuals across the Society who can help better develop our content and communicate the many exciting advances that our members are involved in.

I have served the Society in several different roles—in Publications, as Treasurer, and now as VP for Membership and Geographic Activities. I hope to have the opportunity to continue working with stakeholders from across all parts of the Society to better understand how we serve the computing community and continue to improve.

BIOGRAPHY. Forrest Shull is Assistant Director for Empirical Research at Carnegie Mellon University's Software Engineering Institute (SEI). His role is to lead work with US government agencies, national labs, industry, and academic institutions to advance the use of empirically grounded

Dennis J. Frailey continued from previous page

President of ACM (1986-88). As a speaker for the ACM's DSP and the Computer Society's DVP, Frailey has spoken to over 200 chapters on such topics as careers in computing, cycle time reduction, and techniques used by software engineering professionals. He's also served throughout his career as an adjunct professor at several universities, where his recent courses focus on software quality, software metrics, and software project management. Earlier in his career he had publications and taught courses in operating systems, compiler design, and computer architecture.

Frailey has spent much of his professional life bridging gaps between industry and academia. He's an active participant in groups defining academic curricula and bodies of knowledge in computing fields and helped with the formation of several computer science and software engineering programs. He was a member of the Computer Society's Professional Activities Board and vice chair of the Education Activities Board before the two were merged in 2013. He was an ABET accreditation program evaluator for over 25 years, and has won several awards for contributions to computer science and software engineering education. He served on five industry advisory boards for university computer science, computer engineering, and software engineering programs. Frailey has also been active throughout his career in support of conference activities including various committees, keynote addresses, papers, and as program chair for over a dozen conferences. He holds an MS and PhD in computer science from Purdue University.

Forrest Shull continued from previous page

information in software engineering and cybersecurity. Prior to SEI, he was at the Fraunhofer Center for Experimental Software Engineering, where he founded and served as Director of the Measurement and Knowledge Management Division.

He has been a lead researcher on projects for the US Department of Defense, NASA's Office of Safety and Mission Assurance, the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation, and commercial companies.

While Editor in Chief of *IEEE Software* (2011-2014), he launched the digital edition of the magazine, leading to new subscribers. He created the annual Software Experts Summit, which forged connections with local software industry in cities worldwide. He incorporated the free Software Engineering Radio podcast into *Software*, and maintained the high quality which helps each episode reach 40–50,000 downloads. He currently serves as Associate Editor of *IEEE Transactions on Software Engineering*. He has served in leadership roles on IEEE conferences including ICSE, ESEM, and STC.

Since 2015 he has been a member of the Computer Society Board of Governors and three times served on the Executive Committee, where he has helped institute a metrics-based Portfolio Review initiative, which reviews all of the Society's member offerings for vitality and ongoing relevance to membership. He has served as Society Treasurer, Finance Chair of the Publications Board, and VP for Membership. He is an IEEE Senior Member and a Computer Society Golden Core Member.

He received his PhD in 1998 from the University of Maryland College Park. He is the author of 100 peer-reviewed publications and co-editor of a handbook on empirical software engineering.

SECOND VICE PRESIDENT CANDIDATES

Avi Mendelson

POSITION STATEMENT. As the number of IEEE Computer Society members is shrinking and the overall financial situation is not significantly improving, a major change in the "mode of operation" of the Computer Society must be considered. For the past few years, the Board of Governors (BoG) was mainly focused on improving the financial situation of the Society, but now that the financial situation is stabilizing and it seems we are on the right track for recovering, we must start focusing on improving the services we are proposing, on becoming more relevant to our members and be attractive to many other colleagues so that they will join us. In order to achieve all these goals, I established an "Ad Hoc Committee on Growth" that already proposed several specific actions such as: (1) be more sensitive to the needs of emerging countries (e.g., translate titles, abstracts, and maybe even selected papers to other languages), to work with local technological leaders in order to understand their needs; (2) improve education and training programs for technology; (3) encourage innovation and be more relevant to younger generations of researchers and developers; and (4) expand the industrial involvement and to combine it with our educational and academic activities.

The main reason I ask to be elected as a second vice president of the IEEE Computer Society is to allow me having more means to achieve these goals. Since the President of the Society and the first vice president are mainly focused on the operational aspects of the Society, I believe that if elected, I could work closely with them and make sure that the "Growth" related activities will continue to be considered as top priority of our future activities.

BIOGRAPHY. Avi Mendelson is a member of the IEEE Computer Society Board of Governors (BoG). He is an IEEE Fellow and visiting Professor at the Technion and at NTU Singapore. Mendelson has a blend of industrial and academic experience in several different areas such as Computer Architecture, Hardware Security, Hardware Accelerators, Power Management, Reliability and HPC.

He graduated from the CS department, Technion, BSC and MSC, and got his PhD (1990) from University of Massachusetts at Amherst.

Jon Rosdahl

POSITION STATEMENT. The Computer Society is in a trying time. The financial realities require strict adherence to principles of frugality while entertaining methods of expanding our fiscal stability. I believe that identifying ways to be a better steward of the Computer Society resources while finding new ways to reach out to meet the needs of the membership is required. Reducing expenses cannot be the only solution, however, we should maintain a budget, avoid new debt, and save against a time of shortfall. We need to articulate the value proposition of the Computer Society to its members to engage them in not only contributing to Conferences or Publications, but realizing the support of the members' career paths.

Having served on a variety of committees, I have seen firsthand the need to use open ears and limited opinion to find consensus. Committee meetings should be able to find a consensus of the group by hearing the variety of options and then applying a judgement to find a consensus point. Members of the committee should remain focused and concise in expressing their viewpoints. I believe that my experience has given me the tools to help facilitate progress in hearing all points of view and then making a decision which will be for the benefit of the society.

I look for your vote in support of this opportunity to shape the future of the Computer Society. I believe that values can be understood, solutions can be found, and together a stronger organization will be achieved for the benefit of the members.

BIOGRAPHY. Jon Rosdahl joined the Computer Society in 1989. He has worked on IEEE 802 standards for 25 years. He has served as the Computer Society's Vice President of Standards Activities for the past 2 years (2017-2018). A Senior Member of the IEEE (2002), Rosdahl currently serves as the IEEE 802 Executive Committee's Executive Secretary (2010-2018). He is also serving as the IEEE 802.11 1st Vice-Chair (1994-1996; 2008-2018), and the IEEE 802.11 Treasurer (2008-2018).

He has been a member of the IEEE-SA Standards Board or subcommittees for over 11 years (2006-2015; 2017-2018), including serving as the 2014-2015 IEEE-SA Standards

Avi Mendelson continued from previous page

Among his industrial jobs, he served as the manager of the academic outreach program at Microsoft R&D Israel where he initiated different innovation-based activities among students. Before, he worked for 11 years as a senior researcher and Principle Engineer in Intel. Among his achievement in Intel, he was the chief architect of the CMP (multi-core-on-chip) feature of the first dual-core processors Intel developed. For this work, he got the Intel Achievement Award (IAA, the highest award at Intel).

Among his academic activities he published more than 130 journal and reviewed conference papers, he co-invented the notion of "value prediction" and made major contributions to the field of computer architecture.

He has served as a Computer Society BoG member since 2017. He initiated and ran the "Ad-Hoc Committee for Future Growth of the Computer Society," he serves as the chair of the Transactions Operations Committee (TOC) and as a member of the several other IEEE Computer Society committees.

Mendelson served a full term as an associate editor of the *IEEE Computer Architecture Letters* (*CAL*) journal and currently serves as an associated editor of the *IEEE Transactions on Computers*. As part of his volunteering activities for the IEEE he also served as a member and as the head of the selection committee for the Eckert-Mauchly award.

Jon Rosdahl continued from previous page

Board Vice Chair, the 2014-2015 ProCom Chair and the 2011-2013 NesCom Chair. He served as a member of the 2016 Communications Society Standards Development Board. He currently is a member of RevCom (2009; 2017-2018) and is the IEEE-SA Liaison to the IEEE Technical Activities Board (TAB) (2018).

For 3 years, Rosdahl was Vice-President of WiMedia Alliance and the Treasurer of ZigBee Alliance and held leadership roles in the I2O SIG. He has also served on the Utah State University Electrical and Computer Engineering (ECE) Industry Advisory Committee for 19 years.

Rosdahl has worked on networking, computer, and communication projects throughout his career while working for Novell, Micro-Linear, Vernier Networks, Samsung, and CSR Technologies. He has worked as a software engineer, a technology team leader, manager, and standards engineer. He is currently employed by Qualcomm Technologies, Inc., as an Engineer, Senior Staff.

Rosdahl is an IEEE Computer Society Golden Core Member (2017). He has volunteered and received numerous recognition from the Boy Scouts of America over the past 30 years.

Rosdahl holds a Masters of Engineering, Electrical Engineering (ME EE) (1990) and a Bachelor of Science, Electrical Engineering (BS EE) (1989) degrees from Utah State University.

BOARD OF GOVERNORS CANDIDATES

M. Brian Blake

POSITION STATEMENT. Through its publications, conferences, and services, the IEEE-CS impacts how researchers and professional engineers enhance society. With social media and peer-to-peer networks, the nature of communication is evolving at an unprecedented pace. IEEE-CS must continually enhance its processes and systems so that the knowledge is effectively transferred for the greatest societal impact.

My role as the Executive Vice President and Nina Henderson Provost at Drexel University provides access to over 1,700 partnerships that the institution has with companies, government agencies, and other comprehensive research institutions through our cooperative education network. As a 12-year higher education administrator, my experience includes governance and inter-organizational agreements, which should facilitate my ability to encourage consensus with other governors. My research is in the area of web services for data analytics and social media, which will be important for IEEE-CS as the nature of communication and data dissemination evolves significantly.

As a Board of Governors member, I plan to leverage my diverse experience working in industry, academia, and government agencies and experience with leadership roles for IEEE-CS conferences, publications, and technical committees. Like my work as EIC, I want to help develop approaches that make the Computer Society's body-of-knowledge most accessible to society.

BIOGRAPHY. M. Brian Blake is Distinguished University Professor of Systems and Software Engineering and Executive Vice President and Nina Henderson Provost at Drexel University. Blake has appointments in the Department of Computer Science and the Department of Electrical and Computer Engineering. He is most known for his research and professional contributions to the areas of adaptive, inter-organizational workflow for web services and systems. Blake and his students have co-authored over 200 research papers and received more than $12 million in sponsored research awards.

For IEEE activities, Blake has served as General/Program/Workshop Chair for more than 50 IEEE conferences. He is currently serving as Editor-in-Chief for *IEEE Internet Computing* where he introduced the "Test of Time" paper award and the Editor Select paper series. He was Associate Editor of *IEEE Transactions on Services Computing* and served as vice-chair for the IEEE-CS Technical Committee on Business Informatics and Systems (TCBIS). He served as an IEEE-CS Distinguished Visitor and also Chair of the Coalition for Diversifying Computing which is a joint IEEE/CRA/ACM committee. Blake also co-founded the IEEE Web Services Challenge (IEEE CEC 2004-2011) and the Virtual Instructors Pilot Research Group of the IEEE-CS Technical Committee on Learning Technology.

Blake has served on five National Academies' studies and on the NSF Advisory Committee for the Computer and Information Science and Engineering (CISE) Directorate. Prior to academia, Blake spent six years as a software architect with Lockheed Martin, General Dynamics, and The MITRE Corporation. Blake has a Bachelor of Electrical Engineering from Georgia Tech and a PhD in Information and Software Engineering from George Mason University. He is a Senior Member of IEEE and an ACM Distinguished Scientist. More information is available at http://drexel.edu/provost/about/provost/.

Gregory T. Byrd

POSITION STATEMENT. As a longtime member of IEEE and the Computer Society, I am proud to be associated with an organization that does so much to promote research, education, and standards in our profession. As a Board member, I will encourage investment in new ideas, within our financial constraints and consistent with our mission. I specifically believe that we must focus on actions that encourage membership, especially among young professionals, and which foster collaborations among all content types: conferences, publications, standards, and educational products. We must be good stewards of the reputation and resources of the Society, acting on behalf of the global community that we represent.

BIOGRAPHY. Gregory T. Byrd is Professor and Associate Head in the Department of Electrical and Computer Engineering at North Carolina State University in Raleigh, NC. His research is in parallel computer architecture, and he has also worked in the areas of network processors, network security, and wireless sensor networks. Byrd has served as Director of the Center for Efficient, Scalable, and Reliable Computing (CESR) at NC State, and he received the Outstanding Teaching Award from both the ECE Department and the College of Engineering. Prior to joining NC State, he worked at Celotek, MCNC, NC Supercomputing Center, and Digital Equipment Corp. He received MS and PhD degrees in Electrical Engineering from Stanford University, and a BS in Computer Engineering from Clemson University.

Byrd is a Senior Member of IEEE. He has served on the IEEE Computer Society Board of Governors since 2015, including terms as Secretary (2016), 2nd Vice President (2017), and 1st Vice President (2018). He was a member of the Publications Board (2012-16), and has served as the VP for Publications for the past two years (2017-18). As VP, he has represented the Computer Society on the IEEE TAB Periodicals Committee and the IEEE Publications Services and Products Board (PSPB). He currently serves as a CS representative on the board of the Computing Research Association (CRA). He has been the general co-chair (2012-13) and program co-chair (2011) of the IEEE International Conference on Computer Design (ICCD), and he has been a member of the technical program committee for several IEEE conferences.

Fred Douglis

POSITION STATEMENT. The Computer Society faces challenges as its role evolves. It has many transactions and magazines, but there's been a seismic shift from individual subscriptions to institutional digital subscriptions. It runs many conferences, but these compete not only with other professional societies but with each other. As a member of the Board of Governors, I have been working with representatives from academia and industry on the CS "Research Advisory Board" to reimagine how future academic publishing can be achieved sustainably. A few conferences have moved to a floating schedule that decouples submission from presentation: a paper can be revised and resubmitted to the same conference. The distinction between "archival" publications with major revisions and "conferences" with one submission deadline is ending; what else can the CS do to improve on the conference experience, not only for authors, but for organizers and participants?

As one example, I've been pushing to adopt the policy USENIX uses, wherein a conference attendee who pays the non-member rate can apply the increased cost toward Society membership. As another, I think the economies of scale of centralized registration and publicity should make it possible to have the Society, rather than reluctant volunteers, manage conference bureaucracies at minimal marginal cost.

BIOGRAPHY. Fred Douglis is a current member of the CS Board of Governors and a Fellow of IEEE. He has been a Chief Research Scientist at Perspecta Labs since January 2018, where he works on applied research in the areas of blockchain, network optimization, and security.

He was previously with companies including Matsushita, AT&T, IBM, and (Dell) EMC. His research interests included storage, distributed systems, web tools and performance, and mobile computing. He was also a visiting professor at VU Amsterdam and Princeton University. He has published one book, about 60 workshop or conference papers, 12 journal or magazine articles, and over 80 patents. He holds a PhD in computer science from UC Berkeley.

Douglis has volunteered with the IEEE-CS since 1993, and he was named a member of the Golden Core in 2012. He served as EIC of *IEEE Internet Computing* from 2007-2010 and has been on its editorial board since 1999. He is also on the editorial boards of *IEEE Transactions on Computers and IEEE Transactions on Cloud Computing*. He formed the TC on the Internet, chairing it from 1997 to 2000, and he previously chaired the TC on Operating Systems from 1996 to 1998. He chaired several steering committees; helped organize the first IEEE/IPSJ Symposium on Applications and the Internet (SAINT) in 2001, serving as program co-chair; and he was general chair of the 1993 IEEE Workshop on Workstation Operation Systems.

Outside IEEE-CS, he has been program chair of four major conferences. He serves on the editorial board of ACM's *Transactions on Storage*. He serves on the steering committee of the USENIX Workshop on Hot Topics in Cloud Computing. He received an IBM Outstanding Technical Achievement Award for System S (2008) and a best paper award for the World Wide Web Conference (2004).

Vladimir Getov

POSITION STATEMENT. The IEEE Computer Society (CS) continues to enhance its global membership diversity as we play a central role in the unprecedented digital revolution and lead exciting new IEEE initiatives, such as Rebooting Computing, Cybersecurity, Cloud Computing, Big Data, and Internet of Things. These rapid developments involve several important challenges, amongst which more efficient professional communications via social networks and systematic support and training for young professionals. Nowadays, the introduction of such new initiatives and approaches can only be successful as part of a truly global collaboration reaching around the world—from California, Brazil, and India, to Japan, China, and Europe.

Over the years, I have developed an extensive and unique track record of international achievement and

recognition, involving an increasing number of strong professional contacts in various parts of the world. I have been actively involved in the portfolio review of our periodicals and conferences and am committed to contributing further towards their close collaboration and integration as some of the differences between journal and conference papers will disappear with the transition to e-publications. I will be honored to represent the professional community as CS BoG member and will work with enthusiasm and dedication to address these important challenges.

BIOGRAPHY. An active IEEE Computer Society (CS) volunteer since the mid-1990s, Vladimir Getov is professor of distributed and high-performance computing and research group leader at the University of Westminster, London. He is a member of the IEEE CS Board of Governors (2016–2018), and secretary of the CS Publications Board. Getov has been *Computer*'s area editor for high-performance computing since 2008 and has served as general and program chair of several IEEE conferences. He is also Standing Committee member and co-chair of publications for IEEE COMPSAC, as well as Executive Committee member of the IEEE CS Technical Consortium on High-Performance Computing, while also contributing as an active member of the IEEE International Roadmap for Devices and Systems and several other boards and committees.

Getov's career spans both industrial research and academia. After earning his PhD in Computer Science from the Bulgarian Academy of Sciences, Getov was project manager of an IBM PC/XT-compatible computer (1984). In 1989, he moved to England to join the Concurrent Computations Group at the University of Southampton. Since 1995, Vladimir has been an academic staff member at the University of Westminster, where he was awarded the titles Reader (1999) and Professor (2001). He has an extensive track record of international collaboration and achievements, such as founding contributions to the PARKBENCH Committee, the Java Grande Forum, and the Open Grid Forum.

Getov is recognized by his peers for his commitment to service, leadership skills, and dedication to research and related professional activities. He has received several prestigious awards, such as IEEE CS Golden Core Award (2016), Honorary Professor (TU-Sofia, Bulgaria, 2012), IBM Faculty Award (2010), Bulgarian "Pythagoras" Science Award (2009), Outstanding Executive Committee Contribution Award (EU CoreGRID, 2008). He is a Senior Member of IEEE and ACM, a BCS Fellow, and was Governor of ICCC (2004–2007).

Carlos E. Jimenez-Gomez

POSITION STATEMENT. Computing has become the core of the 21st century society. Nowadays paradigms are changing: primary education students become developers, technology and openness allow citizens to collaborate building apps addressed to improve services ... and there are unmet sectors in which technology is now key that need to be part of the CS's focus. If elected, I will support the BoG, led by the CS President, by developing and implementing strategies to meet the 21st century CS members' needs, and by growing the CS's leadership worldwide in sectors that are increasingly key for the CS.

Given my experience, I will focus on practitioners' needs and contributions. I believe that, on a daily basis, they are the first to experience the complexities of a fast-changing, technology-driven world and its impact on their professional activities, conditions, and needs. Practitioners face the need for new jobs and new skills that can threaten their status quo, and the CS should therefore develop new communities and personalized services to meet these needs. I would like to support the Professional & Educational Activities Board to, for example, develop new career paths for members who experience the need to evolve to master new technologies.

BIOGRAPHY. Carlos E. Jimenez-Gomez (@estratic) has been an active IEEE Computer Society member for 15 years. Nowadays, he is serving as IEEE CS Member and Geographic Activities Board Vice-Chair for Special Technical Communities (STC), as well as IEEE CS STC Executive Committee chair. He was founding member of initiatives such as IEEE CS STC on Electronic Government, where he served as Chair, being a current committee member. He was founding member and active volunteer of IEEE UNED Student Branch and, later, over the past decade, he was founding member and Chair of IEEE Technology Management Council Spain chapter, as well as committee member of IEEE Spain section and IEEE Computer Society Spain chapter.

Jimenez-Gomez is internationally recognized for his expertise in information and technology in government. He is Distinguished Lecturer of IEEE Society on Social Implications of Technology (R1), and he has also been Distinguished Visitor of IEEE CS (R8 and R9), having a great experience as representative in Spanish-speaking countries and regions such as Latin America. He authored conference papers and whitepapers, edited a book, and published several book chapters and articles; and he has also been keynote and invited speaker in international conferences and meetings.

As practitioner, he has more than 25 years working in the public sector. He was Vice-Dean of the Official Professional

Association of Technical Computer Engineers of Catalonia (COETIC) in Barcelona, Spain. In the field of information and technology in government he has worked for governments and international organizations in different countries and continents, especially in Latin America. He is co-author of the Ibero-American Interoperability Framework, officially signed by 21 countries in 2010. His research on digital and open justice has been pioneering. His consulting and research interests include digital government, interoperability, smart cities, open justice or data science.

Fabrizio Lombardi

POSITION STATEMENT. Dissemination of scientific knowledge and interaction among researchers and practitioners are essential ingredients for technology advancement in both academia and industry; CS is at the forefront in these endeavors. More than ever its success is indeed the success of all of its constituencies; so, the CS must continue to be inclusively collaborating with other professional organizations to proactively anticipate the diverse needs of its members. My first and only priority is and will remain to provide the best service to our members for enhancing their professional growth. My past accomplishments in publications and conferences are proof of my capabilities; through effective communication, proven leadership, and timely planning I will contribute to the Board of Governors to enable, facilitate and expand compelling new initiatives to all members; I will help to enhance existing organizational structures, improve service and products across technical areas and geographic locations. Engaging volunteers, moving into new technical frontiers, enlarging student activities, these are few of the endeavors that I will be honored to pursue by fostering a collegiate discussion and efficient resolution. My background in technology, education and management will add a further prospective in helping to shape our Society. Respectfully, I ask for your vote.

BIOGRAPHY. Fabrizio Lombardi holds the International Test Conference Endowed Chair at the Department of Electrical and Computer Engineering, Northeastern University, Boston. He has a doctorate in Electronic Engineering from University College London; Lombardi is an IEEE Fellow, a Golden Core Member, a HKN member and twice a Computer Society (CS) Distinguished Visitor. He was a two-term Editor-in-Chief of the *IEEE Transactions on Computers* and the inaugural Editor-in-Chief of the *IEEE Transactions on Emerging Topics in Computing*; currently, he is the Editor-in-Chief of the *IEEE Transactions on Nanotechnology*. For all three periodicals, his leadership has resulted in substantial improvements in qualitative/quantitative metrics such as impact factor, selectivity and number of submissions. Moreover he has been a Guest Editor of 18 Special Issues in IEEE Transactions and Magazines.

He has been appointed on Executive Boards of many non-profit organizations (such as code.org, the non-partisan advocacy coalition for K-12 Computer Science education, as well as the CS (as an elected two-term member of its Board of Governors (2012-2017)) and IEEE (as an appointed member of the Future Directions Committee (2014-2017)). Among the many volunteer positions in the CS, he was the Chair of the 2016 and 2017 Fellow Evaluation Committees. He has contributed to numerous IEEE International Conferences/Symposia/Workshops in leadership positions (30 times) as well as technical program committee member (nearly 250 times).

He has extensively published in computer engineering and nanotechnology (more than 750 papers of which nearly 150 IEEE Transactions); his research has been funded by state/federal agencies and industry, at the national and international levels, while also receiving two IEEE Meritorious Service Awards and five Certificates of Appreciation. Lombardi is the recipient of awards from industry, the IEEE/Engineering Foundation and the Canadian and Japanese Governments; he also serves as a consultant on matters related to education, technology and corporate strategies.

Ramalatha Marimuthu

POSITION STATEMENT. The Computer Society has excelled in being a change agent for the students, young professionals as well as senior professionals in terms of career advancement from the date it was founded more than half a century ago. Personally I have seen many of my students blossoming into responsible career professionals and developing their network with this platform. The fast evolution in technologies have ensured that the expectations of the member community also change towards IEEE Computer Society. As a member of the Board of Governors, I will be a passionate advocate for encouraging networking opportunities for the members, leading to collaboration and cooperation. With my experience in the various boards as a contributor for the past decade, I believe an opportunity to serve the members of the Computer Society will enrich my learning and enable me to work towards realizing the goals of the Society better. Having introduced many novel programs in various committees I served, I hope to focus on increasing member engagement and member satisfaction

through innovative programs and opportunities for networking. I also bring a vast network of contacts from industry and academia through my years of service.

BIOGRAPHY. Ramalatha Marimuthu, currently working in Kumaraguru College of Technology, Coimbatore, India, has vast experience in motivating and training students on skill development and peer networking. Her specialization in developing solutions for societal issues has been recognized by various universities and research organizations all over the world where she has delivered invited talks on her Assistive Technology–based projects. She has grants, funded projects, and publications, which have enhanced her teaching and delivery over the three decades of her teaching career and has won her Best Teacher Award many times. She has served in many leadership roles as Chair of Departments, Controller of Examinations, Chairperson of Evaluation Boards, and Curriculum Development Boards. She has taken over many leadership roles in IEEE including chairing the IEEE Women in Engineering Committee in 2011 and 2012. Currently she is on the Board of Governors of the IEEE Society on Social Implications of Technology and has founded the Women in Engineering subcommittee under the Society. She launched an exclusive project, "Sangamam," for the transfer of technology to rural areas, which focused on improving quality of life for the rural masses. This project won her the Anita Borg Institute Change Agent Award 2012. Based on her work to improve the quality of life for the rural society as well as the people with special needs, she was awarded the 2008 IEEE MGA Achievement Award, and the 2009 Life Time Achiever Award by the Lions Club International, the 2009 Mentor Award by the Secretariate for the Disabled, the Government of Tamilnadu, and the 2012 IEEE MGA Leadership Award. She was awarded the 2014 ABI Systers Pass it on Award for her Returning Mothers project. Recently she won the 2016 WIE Inspiring Member of the Year Award from the IEEE Women in Engineering Committee.

Erik Jan Marinissen

POSITION STATEMENT. Computer hardware and software is ever more pervasive in our daily work and private environments; even though today's form factor often differs from the traditional computer. And, we are just at the start: "you ain't seen nothing yet!" Therefore, the role of the IEEE Computer Society (CS), as the world's leading association of professionals in computing science and technology, should become only more important, catering to information, networking, and career-development needs of the growing legion of women and men in this field. To maintain its relevance, CS needs to embrace even more the technologies that we as professionals help create: as new topics of conferences and publications, but also to reach out to, connect, and empower our (potential) members.

Even if only for reasons of financial sustainability, CS should be as "inclusive" as possible with low thresholds for participation and active support to volunteers. CS should be appealing to academics and industrial engineers alike (as I know from my thirty years in industrial research), all geographic regions (I am European, speak Dutch, English, and Portuguese daily, and have extensive experience and contact networks in North- and South-America and Asia), and all career stages (student, mid-, but also end-of-career).

BIOGRAPHY. Erik Jan Marinissen is principal scientist at IMEC in Leuven, Belgium, the world-leading independent R&D center in nanoelectronics technology. His research on IC test and design-for-test covers topics as diverse as 3D-stacked ICs, CMOS below 10nm, silicon photonics, and STT-MRAMs. Marinissen is also visiting researcher at Eindhoven University of Technology in the Netherlands. In his thirty-year career in industrial research, Marinissen worked previously at NXP Semiconductors and Philips Research in Eindhoven, Nijmegen, and Sunnyvale. He holds an MSc degree in computing science (1990) and a PDEng degree in software technology (1992), both from Eindhoven University of Technology.

Marinissen is member of IEEE's Test Technology Standardization Committee and served as editor-in-chief of IEEE Std 1500, and as founder/chair (currently vice-chair) of IEEE Std P1838 Working Group on 3D-SIC test access. Marinissen served as general/program chair of several large conferences (including ETS'06, DATE'13) and founded and chaired three workshops himself (e.g., 3D-TEST'09-'15). He serves on numerous conference committees and on the editorial boards of *IEEE Design & Test* and Springer's *Journal of Electronic Testing: Theory and Applications*.

Marinissen is (co-)author of 250+ journal and conference papers (h-index: 42) and (co-)inventor of 18 patent families. He is recipient of the Most Significant Paper Awards at ITC 2008 and 2010, Best Paper Awards at the Chrysler-Delco-Ford Automotive Electronics Reliability Workshop 1995 and the IEEE International Board Test Workshop 2002, the Most Inspirational Presentation Award at the IEEE Semiconductor Wafer Test Workshop 2013, the HiPEAC Technology Transfer Award 2015, the SEMI Best ATE Paper Award 2016, the National Instruments' Engineering Impact Award 2017, and the IEEE Standards Association's Emerging Technology Award 2017.

Marinissen has supervised 42 international MSc and PhD students. He is IEEE Fellow, Computer Society Golden Core Member, and member of the Patient Researchers Working Group of the Dutch Parkinson's Disease Association.

Hausi A. Müller

POSITION STATEMENT. IEEE Computer Society (CS) is an outstanding international organization for computing professionals, students, and researchers providing leadership, foresight, influence, and direction in best practices, education, and leading-edge research. CS is a trusted source for computing technology information around the globe. As a CS volunteer, I aim to inspire future generations of engineers and scientists through leadership and contributions in technical committees. I am deeply committed to advancing equity, diversity, and inclusiveness (EDI) at all levels of IEEE.

To be able to respond to the needs of our rapidly changing society and professions, CS must be agile and adaptive in its operations to champion technically and financially sound services and form promising alliances. To sustain CS's excellence, CS must focus on its membership, its sustainable financial future, and the quality of its core assets. CS must continue to earn the trust of computing professionals and provide extensive opportunities for professional networking, career development, and life-long learning.

With my extensive experience as a CS volunteer and service on the CS BoG, I can provide valuable guidance to provide strategies and tactics for CS organizational entities and foster effective strategic planning, technical and financial accountability of boards and committees.

BIOGRAPHY. Hausi A. Müller is a Professor of Computer Science and Associate Dean of Research, Faculty of Engineering, at the University of Victoria, British Columbia, Canada. He joined IEEE as a student member in 1979 and has been an active member of the IEEE Computer Society (CS) for over 30 years. He serves as VP of the IEEE CS Technical and Conferences Activities (T&C) Board (2016–2018), was an elected member of the CS Board of Governors (2015–2017), and will serve as Member of the 2019 IEEE Conferences Committee and IEEE Conference Publications Committee. He was chair of CS Technical Council on Software Engineering (TCSE) and served on the *IEEE Transactions on Software Engineering* editorial board for 12 years.

Müller is chair of the steering committee of the SEAMS conference series (ACM/IEEE International Symposium on Software Engineering for Adaptive and Self-Managing Systems). He was general chair of 23rd ACM/IEEE International Conference of Software Engineering (ICSE 2001) and 30th IEEE International Conference on Software Maintenance and Evolution (ICSME 2014), and recently technical program co-chair of IEEE World Forum on Internet of Things (WF-IoT 2015 & 2018) and 26th Conference of the Center for Advanced Studies on Collaborative Research (CASCON 2016). He is a Fellow of the Canadian Academy of Engineering, a CS Golden Core member, and received the 2016 TCSE Distinguished Service Award. He collaborates extensively with industry as an international expert in software engineering, adaptive systems, Internet of Things, cyber-physical systems, and intelligent systems. He was co-organizer of an event honoring 90 computing pioneers in Canada. Müller received a BS in electrical engineering from ETH Zürich, Switzerland, and an MS and a PhD in computer science from Rice University in Houston, USA. He sings and plays guitar and enjoys hiking and skiing.

San Murugesan

POSITION STATEMENT. The Computer Society (CS) needs to continue to be relevant and valuable to its members and computer professionals at large. It must also successfully address the challenges it faces and meet its members' expectations. These call for novel approaches to the Society's offerings and operations. Drawing on my broad vision and capabilities, I shall drive major transformation of the Society embracing opportunities we have now and by closely working with staff, volunteers, and our stakeholders.

In particular, I'll advocate and champion this transformation by helping the Society implement new initiatives of value to members around the world by judiciously exploiting advances in technology, changing membership profiles, and global trends. I'll foster new measures to address declining CS members, extend our global reach, boost industry and practitioner participation, and raise our revenue. I'll also enrich members' engagement with the Society and among themselves. Furthermore, I'll work towards improving our publications and digital library and offering you regularly much desired curated information and insights on key topics of interest.

Leveraging on my expertise and over 30 years of varied experience and my close association with the Society, I'll make significant contributions to the Board and the Society and thereby to the members.

BIOGRAPHY. San Murugesan is Director of BRITE Professional Services and Adjunct Professor at Western Sydney University, Australia. He is editor-in-chief emeritus of CS *IT Professional* magazine. In a career spanning four decades in academia and industry, he successfully led several academic programs and development of computing

and control systems for Indian satellite programs. He also provided leadership in curriculum design and research and offered consultancy services. He was a Senior Research Fellow at the NASA Ames Research Center and served as professor of computer science at Southern Cross University and Western Sydney University. Prior to these, he worked at the Indian Space Agency in Bangalore for 19 years.

Murugesan has been a valued Senior Member of IEEE and CS for 25 years. He has actively been contributing to the Society as editor in chief, editorial board member, department editor and as member of various committees and boards. He was program and general chair of several international conferences and is currently a member of COMPSAC standing committee. He was a Distinguished Visitor of CS and served as Vice-Chairman of CS NSW Section, Australia. In recognition of his "distinguished and valuable service, commitment to excellence, and wide-ranging significant contributions the Computer Society," he is awarded the Computer Society's second highest service award, Distinguished Service Certificate.

Murugesan is also well recognized for developing and promoting Web engineering and Green IT as new disciplines. He is co-editor of popular Wiley-CS books *Encyclopedia of Cloud Computing* (2016) and *Harnessing Green IT: Principles and Practices* (2012), both of which are translated into Chinese. He has guest edited over 20 special issues of CS publications, and authored over 250 papers. He has a PhD in computer science from Indian Institute of Science. He is a Fellow of the Australian Computer Society and IETE. For further information, see http://bitly.com/sanbio.

Kunio Uchiyama

POSITION STATEMENT. The global environment is undergoing dramatic changes, and the need to solve global issues, such as global warming, energy, food safety, disaster prevention, and aging populations, is now urgent and crucial. Computer technologies are playing a major role in solving these issues, and the collaboration between computing and other fields leads to further innovation. I have no doubt that the IEEE Computer Society, the world's leading community for computer professionals, could be at the center of collaboration with other IEEE societies, academia, and industrial communities to facilitate future societal innovation.

I will use the experience gained through my 40 years in industry, in which I have led national and collaborative projects with universities, served as a BoG member for the Society, and volunteered on many committees and conferences for professional societies, to serve the Society by making it more attractive to its members and people both inside and outside IEEE and by promoting the Society as a forum to initiate collaboration with other societies for future innovation. In particular, as a member of the Asia-Pacific region, where computer technologies and applications are greatly developed, I will contribute to promoting the activities of the Society in this area.

BIOGRAPHY. Kunio Uchiyama received BS and MS degrees in information science from the Tokyo Institute of Technology, Japan, in 1976 and 1978, respectively, and a PhD degree in advanced applied electronics from the Institute in 2001. Since 1978, he has been working for the Central Research Laboratory, Hitachi, Ltd., Tokyo, Japan, on design automation, mainframe computers, microprocessors, multi-core processors, and their applications. He is currently a technology advisor at Hitachi, Ltd., after working as a chief scientist and corporate officer at Hitachi.

He led the research and development on the commercial SuperH microprocessors from the beginning of the 1990s and was awarded the National Medal of Honor with Purple Ribbon in 2004 in recognition of his contribution to the development of commercial high-performance low-power microprocessors. He also received the R&D100 Award and Chief Officer's Award from the Japanese Science and Technology Agency in 1999 and 2000, respectively. He was the leader of a project for the New Energy and Industrial Technology Development Organization, Japan (NEDO) called "Heterogeneous Multi-core Technology for Information Appliances" from 2007 to 2010.

He has been serving as a member and vice chair of the organizing committee of the IEEE Symposium on Low-Power and High-Speed Chips, which has been sponsored by IEEE CS since 2001, and was a general chair of the Asia and South Pacific Design Automation Conference sponsored by IEEE CAS and CEDA from 2014 to 2015. He has been a member of the Board of Governors of IEEE CS since 2016 and of the Industry Promotion Committee of the IEEE Japan Council since 2014. He is a member of the IEEE Computer Society and Solid-State Circuits Society and of IEICE (Institute of Electronics, Information and Communication Engineers). He is a Golden Core Member of IEEE CS and a Fellow of IEEE and IEICE.

IEEE Division V Delegate/ Director Candidates

The Computer Society is represented at IEEE by the IEEE Division V delegate/director and the IEEE Division VIII delegate/director. Division delegate/directors serve multiple roles: they are voting members of the IEEE Assembly, Board of Directors, and Technical Activities Board. Division delegate/directors are elected in alternate years for a one-year term as a director-elect and a two-year term as a director. Decisions made by the IEEE Board of Directors impact the Computer Society and its members/volunteers. To inform Computer Society members about the IEEE delegate/director-elect candidates, the Computer Society is reprinting candidate biographies and position statements. For complete candidate information, visit www.ieee.org/about/corporate/election/division5.html. We encourage all members to participate in this important election.

The IEEE annual election opens on **15 August 2018** and ends at 12:00 pm Central Time USA/17:00 UTC on **1 October 2018**. We encourage you to also cast your votes for the IEEE Computer Society election by 12:00 pm Eastern Time on Monday, **24 September 2018**.

Cecilia Metra
IEEE Computer Society President-Elect

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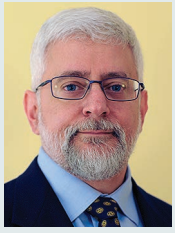
IEEE DIVISION V DELEGATE/DIRECTOR CANDIDATES



THOMAS M. CONTE

POSITION STATEMENT. I'm proud to be part of this 134-year-old institution. But never has it been more challenging to be an IEEE volunteer. Because it has been around so long, IEEE has grown overly bureaucratic. The infrastructure that supports our members is funded by publications revenue and dues. Today all publications must become Open Access: freely available to all. IEEE must become more efficient to survive. Yet, IEEE must not become so obsessed with revenue that we ignore our members' needs.

I joined the IEEE 35 years ago for the same reasons that I'm a member today: to stay current, to keep in touch with colleagues, to contribute and collaborate. As President of the Computer Society, I worked to make the Society more efficient, more responsive to its members, and less rooted in the past. The "is it helping our members?" test has been the guiding principle behind any and all decisions I've made as an IEEE volunteer. It will be the same principle I use as your IEEE Division Director.

BIOGRAPHY. Tom Conte is an active researcher in the field of computer architecture. He received his Bachelor of Electrical Engineering degree from the University of Delaware in 1986; and he received his MS and PhD degrees in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1988 and 1992, respectively. From 1995 to 2008, he was on the faculty of the department of Electrical and Computer Engineering and Director of the Center for Embedded Systems Research at North Carolina State University. While on leave from NC State in 2000-2001, Tom served as the Chief Microarchitect for DSP startup BOPS, Inc. He is currently a Professor joint appointed in the Schools of Computer Science and Electrical & Computer Engineering at the Georgia Institute of Technology where he directs the interdisciplinary Center for Research into Novel Computing Hierarchies focused on post-Moore's Law computing. Conte is the named inventor on 40 US Patents.

JEAN-LUC GAUDIOT

POSITION STATEMENT. As professionals, we have had tremendous impact upon the world. We have changed the nature of daily life for a large portion of humanity. Our field has changed because of the technology that we ourselves have created. Times are changing, yet the mission of IEEE remains: we must provide information and services to advance the theory, practice, and application of science and technology for the benefit of our members and of society at large. Our obligation is to fulfill this role and to prepare the next generation to be good stewards of this knowledge.

Societies, Councils, Chapters, and Student Chapters are the strengths and the essence of IEEE. As Division Director Representative of the Computer Society, I will strive to strengthen these units so they not only continue developing our core products but also explore and exploit new opportunities and technologies to promote the services which are the hallmark of our organization. As a skilled leader, I will seek to be a unifying force that will coalesce opportunities into a coherent vision of our future.

BIOGRAPHY. Jean-Luc Gaudiot is Distinguished Professor of Electrical Engineering and Computer Science at the University of California, Irvine (UCI). He is a Fellow of IEEE and AAAS, and a Professional Member of Eta Kappa Nu.

At UCI, he was Department Chair for 6 years during which the USNWR® rankings rose from 42 to 28 (46 to 36 for the EE program) and 12 faculty members were added. Prior, he was Professor of Electrical Engineering at the University of Southern California (USC).

He frequently acts as consultant to companies that design high-performance computer architectures and as expert in patent infringement and product liability cases. His research interests include the architecture of multiprocessors, a domain in which he has published over 250 papers. His research has been sponsored by NSF, DoE, and DARPA, as well as industrial organizations. He received a PhD in Computer Science from University of California, Los Angeles, in 1982.

IEEE PRESIDENT-ELECT CANDIDATES

IEEE President-Elect Candidates Address Computer Society Concerns

As the largest IEEE society, the Computer Society (CS) serves computing and IT professionals at all levels of their careers, through IEEE's network of more than 400,000 members in 160 countries. The IEEE president and Board of Directors define a vision for the association, and therefore, the decisions they make and plans they put in place impact us as CS members and volunteers.

To ensure CS members are well informed about the candidates on the 2019 IEEE election slate, the CS asked each of the IEEE president-elect candidates for their responses to four important questions that impact our Society and membership. The questions and candidates' responses (limited to 150 words each) are provided here. Please take a few moments to read what these candidates have to say, and be sure to vote in the election, which begins on **15 August 2018** and ends at 12:00 pm Central Time USA/17:00 UTC on **1 October 2018**.

For full information on IEEE President-Elect candidates, along with their personal statements and lists of accomplishments, please visit: www.ieee.org/about/corporate/election/president-elect.html.

In addition, we encourage all members to participate in this important ballot process. We also remind and encourage you to cast your votes for the CS election by 12:00 pm Eastern Time on **24 September 2018**.

—Cecilia Metra,
IEEE Computer Society President-Elect

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IEEE PRESIDENT-ELECT CANDIDATES

TOSHIO FUKUDA

(Nominated by Petition)

Toshio Fukuda studied at Yale University 1973-1975 and received a PhD from the University of Tokyo in 1977. Presently he is Professor of Meijo University and Beijing Institute of Technology as well as Professor Emeritus at Nagoya University. He is mainly engaged in intelligent robotic systems and micro-nano robotics, and he has published 2,300+ publications in scientific journals, conference proceedings, and reports. He served as VP of IFSA (1998-2003) and President of SOFT (2003-2005). He was awarded Humboldt Research Prize (2003); Award from Ministry of Education, Science and Technology, Japan (2005, 2013); Friendship Award from PR Chinese Government (2014); Medal of Honor with Purple Ribbon, Government of Japan (2015). He is a member of Japan Council of Science (2008-2014), Japan Academy of Engineering (2013), and Foreign Member of Chinese Academy of Sciences (2017).

VINCENZO PIURI

(Nominated by IEEE Board of Directors)

Vincenzo Piuri (IEEE Fellow, 2001) is Professor of Computer Engineering at University of Milan, Italy (since 2000; Department Chair in 2007-2012). He has been Associate Professor at Politecnico di Milano, Italy (1992-2000), visiting professor at University of Texas at Austin, USA (summers 1996-1999), and visiting researcher at George Mason University, USA (summers 2012-2018). He founded a start-up company for industrial intelligent systems (CEO in 2007-2010).

His research and industrial interests are in intelligent systems, artificial intelligence, neural networks, pattern recognition, machine learning, signal/image processing, measurement systems, and fault-tolerant architectures. He has published 400+ research papers in international journals, conference proceedings, and books.

He has received several awards and recognitions for scientific contributions and IEEE service. He is an IEEE Fellow, ACM Distinguished Scientist, IEEE-HKN Member, INNS Senior Member, and active Member of IEEE Societies/Technical Councils/Affinity Groups (CIS, ComSoc, CS, CSS, EMBS, IMS, PES, PHOS, RAS, SMCS, SPS, BIOMC, SYSC, WIE).

JACEK ZURADA

(Nominated by IEEE Board of Directors)

Jacek Zurada is a Professor of Electrical and Computer Engineering at the University of Louisville, Louisville, Kentucky, USA. He was a post-doc at Swiss Federal Institute of Technology, Zurich, a Visiting Professor at Princeton University, and a Distinguished Visiting Professor at NUS and NTU (Singapore).

He has authored several textbooks including the pioneering neural networks text and over 420 refereed publications in deep learning, neural networks and image/signal processing that have resulted in over 11,900 citations. He has advised 22 PhD students, now leaders in academia, Google, Facebook, and Amazon. He has also served industry and startups as a consultant.

Zurada has delivered over 160 invited plenary conference presentations and seminars, including Distinguished Lectures for three IEEE Societies. He received numerous IEEE, university, and scholarly society awards for research, teaching, and service. He was elected to the Polish Academy of Sciences and received six honorary doctorates and professorships.

QUESTION 1

What are your financial plans for Societies and Councils that could also impact the Computer Society?

Toshio Fukuda

In my presentation on June 7/8, I included the financial plan to make the IEEE membership double and even a million in future, such that every member will become a TAB Society member, and we introduce the industry corporate membership and micro volunteering (IEEE points) and so on. For the Computer Society, the current membership of 60,000+ is expected to increase by implementing my proposals of corporate membership and so on, in particular, industry membership could increase more from 40 to 50 percent+ in CS within a few years. Since the competing association, ACM, does not have such a system, it will make a big difference. We expect more media-type industries will join IEEE. They are data science oriented, so they will join the Computer Society as their first priority. Those will give great positive feedback and impact on the finances of the Computer Society.

Vincenzo Piuri

Improve financial and decision transparency by: ensuring pervasive and deep participation of diverse-thinking volunteers and Organizational Units in decision processes; clarifying budget structure and allocation rules; adopting a service-center model to understand cost allocation for services.

Reduce overhead by: IEEE-level spending review for optimizing global expenses; IEEE-level project review for reducing unnecessary expenses.

Reduce expenses by: supporting experiments for innovative activities, potentially valuable across IEEE; further sharing services/products/platforms across IEEE for lowering costs; cooperating with national associations to limit investments for joint activities.

Ensure sustainability by: approving new IEEE-level activities only after medium-/long-term financial impact has been analyzed by considering all annually submitted proposals and those previously approved; controlling impact of allocation rules on Organizational Units; refunding investments made to experimental services/products used also by other Organizational Units.

Generate new revenues by creating services with charges to non-members for education, recommendation systems, data analytics, and knowledge extraction.

Jacek Zurada

This question is well-posed since the Computer Society (CompSoc) is a part of the IEEE and has to follow its financial rules. CompSoc will benefit from clearer IEEE accounting principles when it comes to both revenue and expenses. IEEE needs to revise the algorithm that computes revenue from periodicals usage (downloads) and content (number of papers published). To control their financial health, Societies need to know the net for each of their product lines, such as specific periodicals. For more transparency, the cost centers performing services for Societies and Councils should be implemented IEEE-wide.

Although making our finances clearer will make a tangible difference, IEEE needs to look for new revenues. In my platform at www.jacekzurada.org I outline how to bring in new revenue through knowledge extraction from our papers and standards processed by "AI-aligned IEEE Xplore." Driven by data analysis, this new engine will generate new revenue streams.

QUESTION 2
What can the Computer Society do to contribute further to the IEEE?

Toshio Fukuda

IEEE has been looking for new cutting edge technologies in many fields, such as quantum computing and control, bio science, medicine, agri-economics, Earth simulators, and finance, etc. The Computer Society has the key fundamental technology of devices, systems, and software for such development and progress with 200+ conferences and 30 journals/magazines. Today's and future IEEE will heavily depend on the progress of computer technology and applications in many fields, without any doubts, such as bio-information science, AI-based finance, media, trade, automation, and so on for the further technological advances, not necessarily by such conventional conferences and journals but more by Internet/media-oriented tools. Those who make progress in basics and applications of computing in the future will win the game of each field.

Vincenzo Piuri

As Computer Society member for 34 years, I really value its contributions and believe that we can further contribute by: Expanding technical activities in emerging technologies, applications, and standards.

Collaborating in defining personalized bundles of services and products for each individual by: expanding the multi-tier membership model; experimenting with a point-based model in which fees give points to be freely used by each individual to build her own bundle, selecting items that best respond to individual needs; experimenting membership fees proportional to the average income in each geographical area; experimenting a tangible rewarding system for volunteers.

Focusing more on the specific needs of geographical areas and groups.

Expanding experiments on innovative services/products (especially for professionals of the future and industries), including recommendation systems, data/algorithm/experiment repositories, knowledge extraction, data analytics and mining.

Expanding cooperation with other Organizational Units in emerging technologies, applications, services/products, and membership models.

Jacek Zurada

The Society's primary mission is to deliver trusted knowledge in computer hardware and software and create a vibrant community around these technologies. The best contribution CompSoc could make to IEEE, is to be the global front-running Society in computing-related technologies. Here, increased strategic partnerships of CompSoc with leading industries would greatly help. This goal will be easier to achieve if we could incentivize more industrial practitioners to join the Society as members. This, in turn, can happen if the CompSoc offers an attractive portfolio of products and services for computer professionals such as life-long learning, certification courses, and retraining opportunities.

In addition, industrial members can be attracted by networking opportunities, strong Chapters, and vibrant local activities. Finally, emerging areas such as the Internet of Things (and of Everything), Cloud Computing, Big Data, Cyber-physical Systems, Autonomous Symbiotic Systems, and others create very favorable incubators for new communities and tremendous growth.

QUESTION 3
What are your plans to increase women's and young professionals' engagement with IEEE?

Toshio Fukuda

By increasing the corporate membership in industry as proposed, IEEE should make the efforts so that industry will recognize the "value" of IEEE for their own development and progress, so that women and young professionals can comfortably get involved in IEEE activities. Even though women and young professionals in many sectors, such as industry, academia, government, self-employment, and new entrepreneurs are busy, they will be involved in IEEE activities by micro- and nano-volunteering with IEEE points. They can be involved in an IEEE event to varying degrees, even in chapter or TC levels. They can collect and use those IEEE points for any of their own activities. The key is how to establish the firm "relationship" with their organization to ensure the better understanding and recognition of the IEEE "Value" as we adapt to the requirements and wishes of their organization.

Vincenzo Piuri

Ensure impact in IEEE: more presence in technical and management committees; more cooperation among their groups in Societies/Councils and Regions/Sections.

Develop services and products: affordable continuing education; affordable access to knowledge; personalized networking and mentoring for professional development; soft skill training and career building with recommendation systems; repositories for competences and job opportunities; networking jointly organized by Societies/Councils and Regions/Sections to increase technical content; sharing best practices.

Membership fees: free WIE membership to women; more gradual student-member fee transition; membership fees affordable everywhere; monthly payments.

Volunteering: opportunities personalized by time, skills, and aspirations; cooperation with life members, chapters, and student branches.

Recognition: specific awards for technical excellence and service achievements.

Enhance visibility and attractiveness: more activities and cooperation with other associations to promote STEM; promote engineering awareness and relevance among general public; more competitions, makers fairs, humanitarian activities, and engineering projects for community service to make our technological areas tangible.

Jacek Zurada

I believe IEEE can play a bigger role in attracting women to technology-related professions and do better in creating role models of women engineers. We need to better champion profiles of women with successful careers in science, technology, engineering to attract young women to these disciplines. Once members, they should have access to specialized technical and leadership training and networking opportunities. IEEE can hone all these talents.

Unfortunately, our membership has been aging for some time. We have a low 38 percent retention of IEEE student members when they transition to Young Professional status. To reverse this trend, I recommend to reduce IEEE membership fees for students for their first few years after graduation, allowing them to help pay lower dues at a time when they're starting to pay off their student loans. I will also focus on improving services for Young Professionals to better fit their career aspirations.

QUESTION 4

What are your plans to increase industry professionals' and entrepreneurs' engagement with IEEE?

Toshio Fukuda

As I proposed, IEEE may introduce the corporate membership in industry, and then industry professionals and entrepreneurs will be able to work comfortably with recognition from industry so that there will be a natural increase in membership. In addition, this will foster a closer relationship with other industry and academia members. These members can share the technical and human relational merits by IEEE activities in the local chapters and TCs, because they all will also join at least one of the TAB societies, as I proposed. Even though they are busy, these members can be involved in local and technical IEEE activities by micro and nano volunteering with IEEE points system. The relationships built by this way are the most valuable asset for IEEE members for the further development and progress of their careers.

Vincenzo Piuri

Develop specific services and products: practical knowledge for professionals; accessible continuing education; sustainable access to knowledge and facilitated search for services/products by recommendation systems and modern distribution channels; personalized mentorship services for career building and development; repositories for competences and job opportunities; personalized networking opportunities.

Expand cooperation with national sister associations, other associations, and incubators supporting entrepreneurs.

Increase opportunities for volunteering: share practical knowledge and best practices; expand industry tracks and use-case presentations at conferences and Sections/Chapters meetings; promote micro-volunteering to personalize efforts by available time, skills, and aspirations.

Expand rewards and recognition: reward industry volunteers with product/services; invite more industry professionals and entrepreneurs as distinguished lecturers; create more awards focusing on industry achievements; increase presence of industry professionals and entrepreneurs in committees on technology and industry needs; make IEEE volunteering and service/products more appealing to industry managers (also offering personalized bundles to individual industries).

Jacek Zurada

This question is of paramount importance, as we need to reverse the trend that shows IEEE is gradually becoming an organization for academics and run by academics: IEEE's industrial membership has dropped from 67 percent to 47 percent since 2000. This trend mirrors the decreasing relevancy of IEEE's offerings for a practicing engineer/entrepreneur. IEEE's crown jewel, IEEE Xplore, doesn't appear to be sufficiently attractive to keep them as members.

Some reforms have just commenced this year with the creation of the Industry Engagement Committee, led by former CompSoc President, Dejan Milojicic (2017), and Eddie Custovic (2018). Further, we may need a new IEEE Distinguished Member grade for accomplished members above the Senior Grade. If elected, I'll champion personalizing the intellectual property for industrial/entrepreneur members. It needs to be formatted as knowledge and pre-processed/pre-filtered with AI/ML tools. This will transform IEEE from "paper provider" to "knowledge provider." More at: www.jacekzurada.org.

CS CONNECTION

JEFF REARICK AWARDED THE 2018 IEEE COMPUTER SOCIETY HANS KARLSSON AWARD

Jeff Rearick, Senior Fellow at Advanced Micro Devices (AMD), has been awarded the 2018 IEEE Computer Society Hans Karlsson Award. He is recognized for "his vision, extraordinary skills and dedication in leading, shaping, and promoting the IEEE 1687 standard that provides access to embedded semiconductor instrumentation."

At AMD, Rearick and his team are responsible for the Design-For-Testability strategy and roadmap for the company. Over the course of his career, he has worked on many aspects of integrated circuit testing, from hands-on testing of microprocessors, to test automation tools, to DFT architecture. His work includes the design and use of on-chip instruments for testing complex digital functions and analog/mixed-signal circuits such as high-speed I/Os and delay-locked loops.

Rearick extended his embedded test work by co-founding the IEEE SA IJTAG (Internal Joint Test Action Group), whose efforts became standardized in 2014 as IEEE 1687 (*Access and Control of Instrumentation Embedded within a Semiconductor Device*), for which he served as the editor. In recognition of the impact of that work, Rearick received the 2016 Bob Madge Innovation Award at the International Test Conference. He built on that momentum by co-founding three currently active working groups: IEEE P1687.1 for the re-use of functional interfaces and controllers to access 1687 networks, IEEE P1687.2 for describing analog test access and control (for which he is again serving as editor), and IEEE P2427 for analog defect coverage measurement.

Rearick received a Special Recognition Award for his efforts in the development and first silicon demonstration of IEEE 1149.6 (AC Boundary Scan) and a Certificate of Appreciation for his role in IEEE 1804 (Fault Coverage and Accounting). He is a longstanding member of the IEEE Test Technology Standards Committee.

In addition to his standards work, Rearick has served on the program committee of the International Test Conference for 10 years and has contributed to the program committee of the European Test Symposium. He holds over 40 US patents, and has presented dozens of technical papers, invited addresses, and keynotes at various conferences. Rearick earned BSEE and MSEE degrees from Purdue University and the University of Illinois, respectively.

The award consists of a plaque and a $2000 honorarium, and is awarded annually to the most outstanding team leader in the field of computer engineering standards. It recognizes outstanding skill, and a dedication to diplomacy, team facilitation, and joint achievement in the areas where individual aspirations, corporate competition, and organizational rivalry would otherwise be counter to the common good.

The award was presented at the IEEE Computer Society's annual awards ceremony on 6 June 2018 in Phoenix.

GOOGLE CO-FOUNDERS SERGEY BRIN AND LARRY PAGE TO RECEIVE THE IEEE COMPUTER SOCIETY 2018 COMPUTER PIONEER AWARD

Sergey Brin and Larry Page, Google's cofounders, have been selected to receive the IEEE Computer Society's 2018 Computer Pioneer Award.

This award acknowledges significant contributions to early concepts and developments in the electronic computer field that clearly advanced the state of the art in computing. Brin and Page are being recognized "for the creation of the Google search engine and leadership in creating ambitious products and research initiatives."

Together, Brin and Page developed the PageRank algorithm and used it to build Google's search engine, which is now the most-used search engine in the world. Two heavily cited papers describe their early work:

- S. Brin et al., "The PageRank Citation Ranking: Bringing Order to the Web," 1999; http://ilpubs.stanford.edu:8090/422/1/1999-66.pdf.
- S. Brin and L. Page, "Anatomy of a Large-Scale Hypertextual Web Search Engine," Seventh International World Wide Web Conference, 1998; http://ilpubs.stanford.edu:8090/361/1/1998-8.pdf.

Brin and Page co-founded Google and its parent company, Alphabet, and Brin currently serves as Alphabet's president and Page as Alphabet's chief executive officer.

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Since their initial technical work, both have been heavily involved in steering Google and Alphabet's technical portfolio of products and research projects, often making significant and convincing arguments to other Google engineers about why a particular project that seemed implausible or infeasible was actually achievable and worth pursuing. Examples include Google Street View ("Let's add photos to maps so people can see what a street looks like in real life"), Google Books ("Let's scan all of the world's books and make their contents searchable"), Google's self-driving car project (which began in 2009, much earlier than other commercial efforts in this area), and many others.

Fellows of the American Academy of Arts & Sciences, both Brin and Page have recievend of the Marconi Foundation Prize and are members of the National Academy of Engineering.

Brin received degrees in mathematics and computer science from the University of Maryland and Page earned a degree in engineering from the University of Michigan.

They met at Stanford University, where both were PhD students in the Computer Science Department. As a research project, they developed an algorithm that counted the number and quality of links to a webpage to determine a rough estimate of how important the website is. This was used to rank websites in the search engine they developed—which they named Google, as it was inspired by the mathematical term "googol," to reflect their mission to organize the immense amount of information available on the Internet.

The Computer Pioneer Award was established in 1981 by the IEEE Computer Society Board of Governors to recognize and honor the vision of those whose efforts resulted in the creation and continued vitality of the computer industry. The award acknowledges outstanding individuals whose main contribution to the concepts and development of the computer field was made at least 15 years earlier.

Past recipients of the award include Frances Allen, Grady Booch, Edgar Codd, Douglas Engelbart, Edward Feigenbaum, Tony Hoare, Robert Kahn, Jack Kilby, Dennis Ritchie, and David Wheeler. Further information about the award, including a list of all past recipients, can be found at www.computer.org/web/awards/pioneer.

CHANGES TO SOCIETY BYLAWS AVAILABLE ONLINE

The IEEE Computer Society Board of Governors recently approved the first reading of an amendment to the Society's bylaws.

The amendment revises Article IX, Section 5, which covers the terms of Editors in Chief (EICs) of Computer Society periodicals to extend the first term for an EIC from two to three years, to allow the EIC more time to accomplish her or her goals before being considered for reappointment. If an EIC is reappointed, the second term remains as two years.

The proposed bylaws section is available for review at https://tinyurl.com/y8wove7v.

Additions are marked in highlighted text. Only relevant segments of the bylaws in question are reproduced. Changes to existing Society bylaws that receive first-reading approval by the Board of Governors are listed by title in *Computer*, with links to a website location hosting the actual documents. The documents remain accessible at this location until such time as the changes receive final approval. Members can send comments to Anne Marie Kelly (amkelly@computer.org) by close of business 30 September 2018.

IEEE SECURITY & PRIVACY WINS 2018 APEX AWARD OF EXCELLENCE

IEEE Computer Society's *IEEE Security & Privacy*, a leading publication in the security technology industry, has been awarded the 2018 APEX Award of Excellence in the "Magazines, Journals & Tabloids – Electronic" category.

APEX awards honor publication excellence through an international competition that recognizes outstanding publications, from newsletters and magazines to annual reports, brochures and websites.

Said one of the APEX 2018 judges, "This special issue addresses the mysterious (to many) issue of 'post-quantum cryptography'—algorithms designed to enhance security against cyber-attacks. Those in the field are provided with a comprehensive summary of current and future challenges, and it goes into great detail covering all aspects of this new technology."

"*IEEE Security & Privacy* is honored to receive the 2018 APEX Award of Excellence," said David M. Nicol, editor in chief and Franklin W. Woeltge Professor of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign. "This award and its predecessor from last year prove the success of our ability to deliver high quality content, on highly relevant topics in a way that is accessible to experts and non-experts alike."

The IEEE *Security & Privacy* July/August 2017 winning issue explores the topic of postquantum cryptography. Because of public-key cryptography's relevance and quantum computers' increasingly realistic threat to this technology, it is necessary to come up with practical and secure postquantum cryptography. This special issue aims to present the state of the art and the grand challenges in postquantum cryptography and to discuss the transition of real-world systems to the new technology.

According to the APEX 2018 panel of judges, this year's competition was exceptionally intense. From over 1,400 entries evaluated, 100 APEX Grand Awards were presented in 12 major categories to honor the outstanding works in those categories, with 556 Awards of Excellence recognizing exceptional entries in 100 individual categories. More information can be found at www.apexawards.com/apexawards.htm.

IEEE Security & Privacy magazine offers peer-reviewed articles and research on the most critical cybersecurity technologies and topics impacting the world. It provides articles with both a practical and research bent by the top thinkers in the field along with case studies, tutorials, columns, and in-depth interviews and podcasts for the information security industry.

IEEE Computer Society Harlan D. Mills Award

Call for Software Engineering Award Nominations

Established in memory of Harlan D. Mills to recognize researchers and practitioners who have demonstrated long-standing, sustained, and impactful contributions to software engineering practice and research through the development and application of sound theory. The award consists of a $3,000 honorarium, plaque, and a possible invited talk during the week of the annual International Conference on Software Engineering (ICSE), co-sponsored by the IEEE Computer Society Technical Council on Software Engineering (TCSE).

Deadline for 2019
Nominations: 1 October 2018

Nomination site:
awards.computer.org

Past Recipient: Pamela Zave

"For groundbreaking use of formal methods in the development of telecommunication software and for enduring contributions to software engineering theory."

The award nomination requires at least 3 endorsements. Self-nominations are not accepted. Nominees/nominators do not need to be IEEE or IEEE Computer Society members.

IEEE computer society

2019

IEEE-CS
Charles Babbage Award

CALL FOR AWARD NOMINATIONS
Deadline 1 October 2018

ABOUT THE IEEE-CS CHARLES BABBAGE AWARD
Established in memory of Charles Babbage in recognition of significant contributions in the field of parallel computation. The candidate would have made an outstanding, innovative contribution or contributions to parallel computation. It is hoped, but not required, that the winner will have also contributed to the parallel computation community through teaching, mentoring, or community service.

ABOUT CHARLES BABBAGE
Charles Babbage, an English mathematician, philosopher, inventor and mechanical engineer who is best remembered now for originating the concept of a programmable computer.

CRITERIA
This award covers all aspects of parallel computing including computational aspects, novel applications, parallel algorithms, theory of parallel computation, parallel computing technologies, among others.

AWARD & PRESENTATION
A certificate and a $1,000 honorarium presented to a single recipient. The winner will be invited to present a paper and/or presentation at the annual IEEE-CS International Parallel and Distributed Processing Symposium (IPDPS).

NOMINATION SUBMISSION
Open to all. Nominations are being accepted electronically at www.computer.org/web/awards/charles-babbage. Three endorsements are required. The award shall be presented to a single recipient.

NOMINATION SITE
awards.computer.org

AWARDS HOMEPAGE
www.computer.org/awards

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