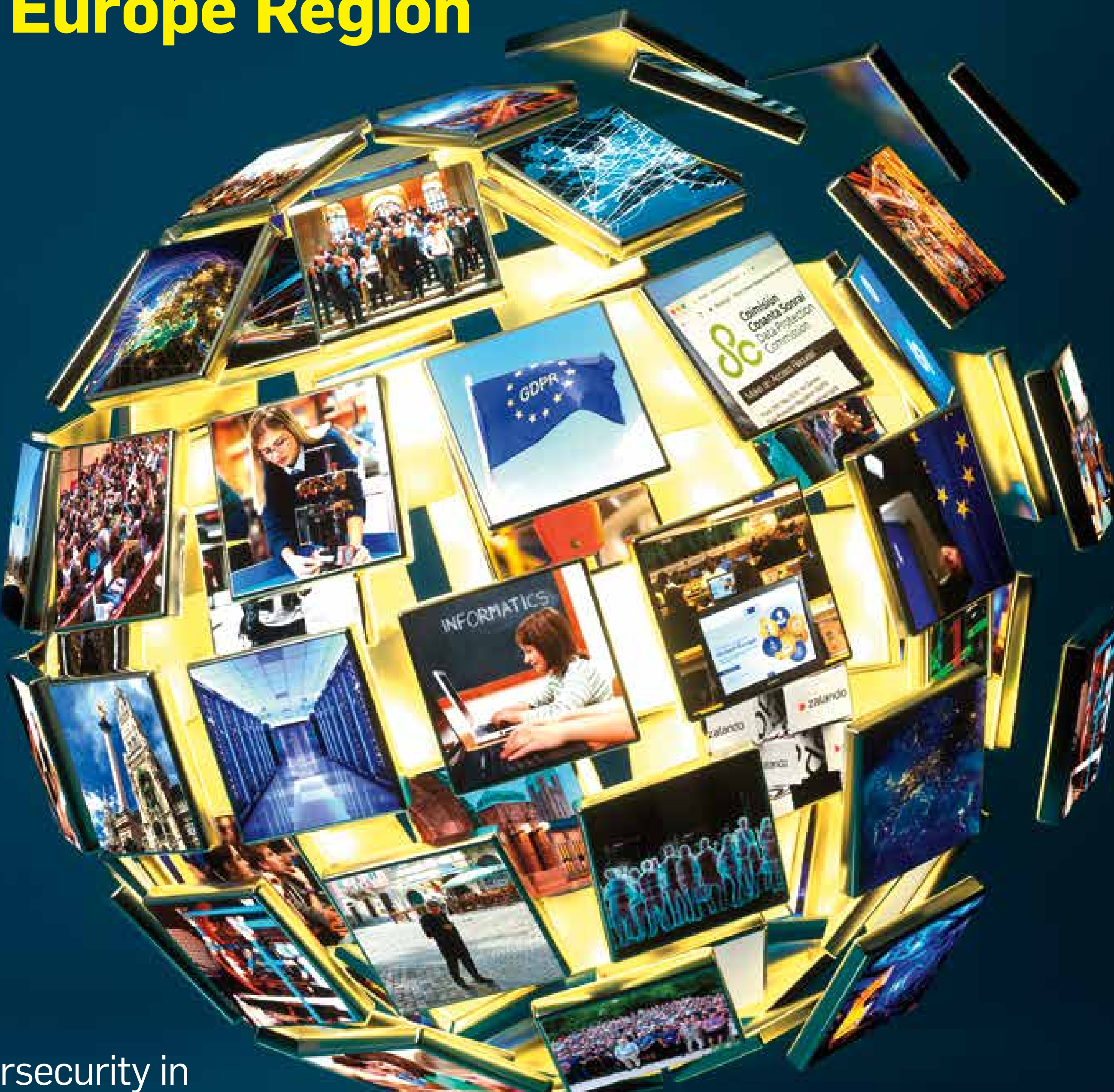
COMMUNICATIONS OF THE ACM

CACM.ACM.ORG

04/2019 VOL.62 NO.04

Special Section on Europe Region



Cybersecurity in the Quantum Era

Metrics That Matter

Analytics for Managerial Work

The Future of Data Storage

Association for Computing Machinery

Europe Region Special Section

THE COMPUTING COMMUNITY throughout the European Region is championing many enterprising industry, academic, and government initiatives to further develop the field and ensure a workforce prepared to take it on.

The articles in this special section, written by some of the leading voices in the region, tell stories of informatics and ICT innovations, Web science in Europe, the EuroHPC, future research directions planned for this vibrant part of the world, and much more.

ILLUSTRATION BY SPOOKY POOKA AT DEBUT ART. FOR CREDITS ON IMAGES IN COLLAGE, SEE P.3.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Data Protection Commission
INFORMATICS
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DOI:10.1145/3309913

Welcome to the Europe Region Special Section

With its population of over 740 million people and 24 official languages, Europe provides a unique environment for the development of a distinctive computing landscape. We believe you will see this reflected in this first Europe Region Special Section.

We invited a mix of practitioners and academics from across the Europe region, not only European Union members but also Switzerland and Israel, to suggest topics for inclusion in this Europe Region Special Section. We brainstormed article ideas with nearly two-dozen colleagues from across the region at a workshop in Paris in July 2018. The article pitches generated at that workshop went through two further rounds of review and refinement. As you will see, the resulting collection of articles offers an excellent view of some of the most exciting activities in the region.

We are proud to present this section which, like the China Region Special Section published last November, consists of two kinds of articles: shorter "Hot Topics" articles that set the context for European developments in computing, and longer "Big Trends" articles that describe exciting developments in areas such as high-performance computing, embedded systems, and computing education. Half of the Hot Topics articles describe the European consumer computing market, the innovation ecosystem, demographics, and the research agenda; the remaining articles briefly describe specific initiatives and recent developments.

Europe has played an important role in the development of the computing discipline, from the pioneering work of Alan Turing and Konrad Zuse through the modern day. The following pages show that it continues to be a vibrant, distinctive part of the global computing community. We are sure the reader will find much of interest in the following pages.

—Panagiota Fatourou and Chris Hankin
Europe Region Special Section Co-Organizers

Panagiota Fatourou is an associate professor in the department of computer science of the University of Crete, Greece, as well as a collaborating faculty member at the Institute of Computer Science of the Foundation for Research and Technology, Hellas (FORTH).

Chris Hankin is co-director of the Institute for Security Science and Technology, and a professor of computing science, at Imperial College London in the U.K.

Back row from left: Yota Papageorgiou, Julie McCann, Steven Newhouse, Joaquim Jorge, Koen De Bosschere, Guillaume Toublanc, Michael Caspersen, Chris Hankin. Front row from left: Fabrizio Gagliardi, Paola Inverardi, Andrew Chien, Panagiota Fatourou, Vassiliki Petousi, Lihan Chen.

Watch the co-organizers discuss this section in the exclusive *Communications* video. https://cacm.acm.org/videos/europe-region

EUROPE REGION

SPECIAL SECTION

Hot Topics

Big Trends

IMAGES FROM SHUTTERSTOCK.COM

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Advancing Computing as a Science & Profession

Workforce | DOI:10.1145/3309915

A Demographic Snapshot of the IT Workforce in Europe

BY LISA KORRIGANE

EUROPE IS NOT a static entity but here is what it looks like in 2019:

The European Union is made up of 28 countries. The capital is in Brussels, Belgium, and the presidency is shared among EU members each semester. In 2019, the first semester sees Romania holding presidency until June, then Finland until the end of the year. An estimated 551.8 million people live in the EU, speaking 24 official languages. Approximately 72% of the population is employed,[a] which is greater than the pre-economic-crisis peak of 2008. Men are more employed than women by an average of 11%.[b]

The ICT workforce in the EU counts some 8.4 million people. The U.K. alone provides almost 20% of this workforce, although it only accounts for 12.8% of the EU population. The second and third providers are Germany and France, but the proportions are more coherent with their population ratios. The number of ICT specialists has grown over 36% in the last 10 years,[c] a significant jump from a mere 3.2% a decade ago. This marked increase helps explain why ICT employment has resisted the effects of the region's overall financial crisis.

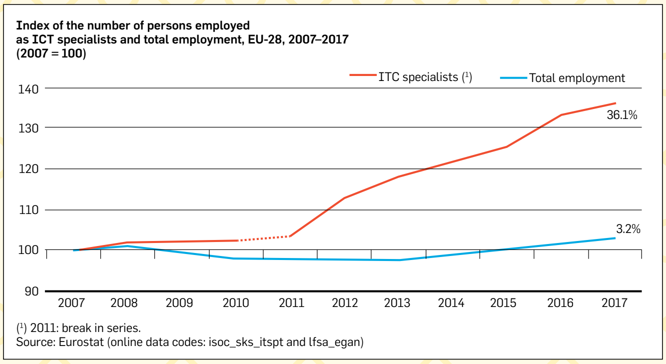
Obviously, the raw numbers favor the most populated countries, but the proportion of ICT specialists in total employment country by country tells a different story, as Nordic countries lead the way. Finland comes first with 6.8% of its workforce dedicated to ICT.[d] In comparison, Germany is much further behind with 3.8%, and France tailing Germany with 3.7%. The other two leaders are Sweden and Estonia with 6.6% and 5.6% of their respective workforces dedicated to ICT. Both Finland and Sweden are home to very efficient teaching methods as they integrated computer studies into their school curricula since the Nokia and Ericsson years. The two mobile phone companies actually spirited a whole generation to place their trust in ICT. As for Estonia, political decisions taken 20 years ago turned the country into "one of the most advanced digital societies in the world."[e] Despite its small size, Denmark is also very active in ICT and has attracted big corporate names, such as Microsoft, Uber, and IBM.

The countries that lead the ICT sector in Europe today are the ones that invested a great deal of time and resources 20 years ago, especially in education.

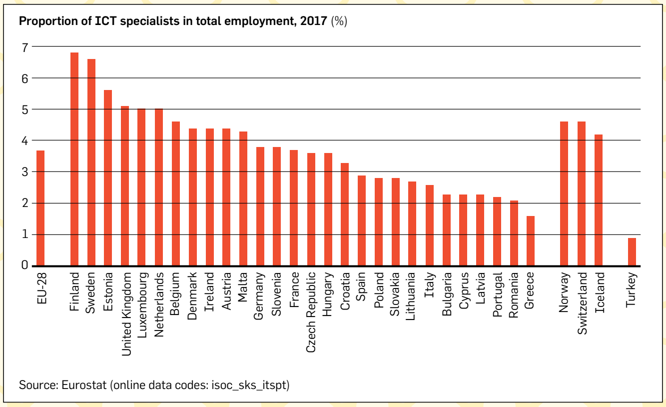
The Typical ICT Worker and the Gender Gap

The overall picture of the European ICT worker can be summed up as follows: A male over 35 with tertiary education diploma. Almost two-thirds of all people employed as ICT specialists in the EU are over 35 years of

a http://bit.ly/2CGkreW
b https://bit.ly/2RYTmNI
c http://bit.ly/2Dr16zI
d http://bit.ly/2S3Lfzo
e https://e-estonia.com



Index of the number of persons employed as ICT specialists.



Proportion of ICT specialists in total employment.

age.[f] Europe does have quite a significant unemployment rate of 65.3% for those under 24 years old. Postsecondary education also plays a role in the ICT population as over 62% of all ICT specialists in the EU have completed tertiary level education,[g] with the highest shares of this attainment found in Lithuania, Ireland, Cyprus, and Spain.

The vast majority of people employed as ICT specialists are men. They account for 82.8% of the total ICT workforce.[h] The number of women in ICT has actually decreased by 5% during the last 10 years, with only slight increases noted in France, Belgium, and the Netherlands. However, Bulgaria has the highest proportion of women in ICT as they account for 26.5% of the workforce. The total proportion of employed women in the EU (across all sectors) is 66.4%, but rises well above those figures in countries like Germany (75.2%), Estonia (75.1%), and Finland (72.4%).

The dear need of ICT specialists. The demand for ICT specialists in the EU is very high. One in five businesses need ICT workers across all sectors of the economy.[i] Larger companies have also reported challenges recruiting skilled ICT workers. In 2017, 48% of nine companies that recruited or tried to recruit reported difficulties in filling vacancies. This applies to all countries in the EU. Depending on projections,[j] the expected shortage of 10 skilled ICT workers in the EU starts at 526,000 individuals in 2020. In the case of a high-growth estimate, this shortage could reach over 900,000 workers. Because the shortage is global, salaries have increased to attract skilled individuals. Salaries in the U.S., however, are much higher.[k] For example, the average salary for a software developer in the U.S. is $92,240 and $43,749 in France. This induces a brain drain of talent, which brings about two pernicious side effects in Europe: lack of senior specialists and lack of qualified trainers for upcoming workers. However, a mere comparison of salaries would be inaccurate. Workers in France pay very little for healthcare and have almost no education expenses (both financed with taxes). Most young workers start their professional life with no student loans to pay back.

The sectors where demands are the highest vary according to studies, but all agree that big data analytics and business analytics[l] are the most sought-after.

Norway, Switzerland, Iceland, and Turkey are not members of the EU, but are located inside or close to the European continent. Is their position in the ICT ecosystem any different from EU members? Norway, Switzerland, and Iceland relate to the EU's average statistics. Turkey, on the other hand, sets itself apart with just 0.9% of its workforce in ICT and only 10% of those are women.[m] Moreover, Turkey has almost two-thirds of its ICT workforce under the age of 34, which is the exact opposite of the EU numbers.

Europe's Efforts to Meet Demand for ICT Specialists

Despite a variety of ICT opportunities available in Europe, it lags behind the U.S. and China. The brain drain mentioned earlier and the difficulty to standardize actions throughout the vast continent hinders efforts to catch up.

Following the demands of top IT scientists in 2018, the European Laboratory for Learning and Intelligent Systems (ELLIS) was founded last December.[n] Focusing mainly on artificial intelligence and, more broadly, on machine learning, they aim to create a network to advance breakthroughs across the continent and educate the next generation of AI researchers.

The U.K. invested £1 billion in artificial intelligence[o] in 2018 and created the Centre for Data Ethics and Innovation to monitor the AI research.

The countries that lead the ICT sector in Europe today are the ones that invested a great deal of time and resources 20 years ago, especially in education. In order to catch up, much effort must be focused on developing computer science in school.

It appears that a huge potential ICT workforce resides with women. They must be encouraged, very early on in school, to embrace ICT careers. This would lead to a more balanced sector, improve women's employment rates, and help reduce the shortage in ICT specialists.[p] C

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g http://bit.ly/2CAWy8f
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i http://bit.ly/2S8aReB
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p http://bit.ly/2FSlziM

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Tech Talent | DOI:10.1145/3309917

Enterprises Lead ICT Innovation in Europe

BY DAVID PRINGLE

IN GLOBAL TERMS, Europe's information and communications technology (ICT) industry is small, overshadowed by the massive U.S. software industry and the extensive electronics industry in East Asia. But it does have some world-class companies, such as telecom equipment providers Nokia and Ericsson, online music platform Spotify, e-commerce company Zalando, enterprise software provider SAP, games developer Supercell (now owned by Tencent), embedded processor designer ARM (now owned by Softbank), and Skype (now owned by Microsoft). Moreover, some of the region's telecom groups, Deutsche Telekom, Vodafone, Orange, and Telefónica, are major multinationals with operations spanning several continents.

Although it has only one of the top 10 artificial intelligence (AI) research institutions[a] (CNRS in France) and no major cloud service providers or Internet platforms on the scale of Amazon, Microsoft, or Google, Europe does innovate in ICT. Non-tech companies, particularly automakers, banks, and pharmaceutical firms, such as BMW, Deutsche Bank, BNP, and Bayer, drive much of this innovation. Whereas Europe's tech industry is cash-strapped, non-tech companies in Europe have more cash holdings than their counterparts in the U.S. or China.[b]

Laura Citron, chief executive of London and Partners, welcomes technology talent from around the world to the 2018 Deep Tech Summit.

> **"Europe is made of tens of different cultures, it's our biggest advantage. The more diversity you can find among entrepreneurs, the more you will find innovative businesses, creativity, and value created."**

As one of the world's leading financial centers, London hosts a thriving fintech industry, which is harnessing big data analytics to personalize financial services. Germany and France are home to many of the world's leading players in transportation, which are adopting ICT rapidly, as they move to semi-autonomous vehicles and ultimately self-driving cars. BMW, Daimler, Siemens, Bosch, and Airbus are among the major European companies embracing the Internet of Things to improve trucks, trains, planes, and cars. For example, the region is leading trials of platooning—the use of wireless technologies to enable semi-autonomous trucks to drive in convoys along motorways, while their drivers take a break. Platooning could cut fuel costs, reduce congestion, and increase efficiency.

Rising Investment in Deep Tech Research

At the same time, the region's tech ecosystem is renewing itself: In Europe, $3.5 billion was invested in so-called deep tech companies in 2017 across more than 600 deals, up from $2.5 billion in 2016.[c] Deep tech refers to software, semiconductors, and other digital hardware. Many of these investments take advantage of Europe's renown computer science institutions—the continent is home to half of the top 10 computer science institutions in the world.[d] Moreover, Europe is producing more than twice the STEM Ph.D's graduating in the U.S.[e]

AI is the hottest area for investment. AI companies in Europe have raised more than $4.6 billion since 2012 across over 1,000 deals. Europe has also spawned several hundred blockchain companies and augmented reality or virtual reality startups since 2012.[f] Helsinki has the second highest concentration of app developers in the world behind the San Francisco Bay area.[g] Minsk in Belarus ranks sixth, Stock-

a Ranked by most cited AI-related research papers. The Nikkei & Elsevier, Atomico State of European Tech 2017; https://2017.stateofeuropeantech.com/

b The S&P CapitalIQ Platform. Atomico State of European Tech 2017; https://2017.stateofeuropeantech.com/

c Dealroom.co. Atomico State of European Tech 2017; https://2017.stateofeuropean-tech.com/

d Times Higher Education World University Rankings 2018. Atomico State of European Tech; https://2018.stateofeuropean-tech.com/

e The OECD. Atomico State of European Tech 2017; https://2017.stateofeuropeantech.com/

f Tracxn. Atomico State of European Tech 2017; https://2017.stateofeuropeantech.com/

g A study by Caribou Digital; http://bit.ly/2REupYi

PHOTO COURTESY OF TECH TOUR

holm eighth, and London ninth on this measure.

"The level of capital available has skyrocketed in the past years," noted Xavier Niel of Station F, in an interview with Atomico. "Europe is made of tens of different cultures, it's our biggest advantage. The more diversity you can find among entrepreneurs, the more you will find innovative businesses, creativity, and value created."

In 2015, the value added by the EU ICT sector amounted to $654 billion, 5.2% more than the previous year.[h] The sector employed 6.4 million people and spent $34 billion on business R&D expenditure.

Major regional disparities in pay. Yet, Europe still sees many of its entrepreneurs and ICT specialists emigrate to North America, either to obtain funding, expertise, or higher pay. On average, software developers in Switzerland earn $85,709—more than anywhere else in Europe, but less than their peers in the U.S. ($92,240). Norway is next with $70,776, followed by Denmark ($70,082), the U.K. ($59,268) and Germany ($57,345).[i] In fact, there are major regional disparities. Whereas the median salary for a software engineer in Berlin, London, and Paris is over $50,000, the equivalent figure in Warsaw is less than half that and just $15,000 in Bucharest. By way of comparison, a software engineer in Tokyo, Japan, earns almost $54,000 on average.[j]

However, by some measures, Europe is better than other regions at harnessing its talent. Indeed, some of Europe's education systems are the envy of the world: Estonia and Finland are in the top five globally, while 13 European countries rank above the U.S. in terms of education outcomes, according to the PISA 2015 study of 15-year-olds' performance in math, science, and reading. ■

h The European Commission, https://bit.ly/2sGADYP

i Daxx.com; https://bit.ly/2FKh7Dl
j Glassdoor; https://bit.ly/2RKEKBZ

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ICT Plans | DOI:10.1145/3309919

Europe's Ambitious ICT Agenda

BY DAVID PRINGLE

FOR EUROPE, INVESTMENT in advanced ICT is a must. With an aging population and a shrinking workforce, Europe needs to tap artificial intelligence (AI), 5G wireless connectivity, quantum computing, and other ICT technologies that could drive the next step change in productivity.

To that end, the region can build on a long-standing scientific tradition. Thanks in part to sustained public sector support, Europe is a leading producer of high-quality scientific research. Its scientists excel in aeronautics, transport technologies, and energy and construction, based on the number of widely cited publications.[a]

PHOTO COURTESY OF ELLIS SOCIETY

Leading European AI researchers assembled in Montreal last December to announce the establishment of a society to found a cross-national European Laboratory for Learning and Intelligent Systems (ELLIS).

As a densely populated continent, Europe is at the forefront of urban planning and the development of smart transport systems. London's $20 billion Crossrail project, which plans to introduce new intelligent on-train management systems to reduce energy costs by up to 20%, is one of many examples of Europe's commitment to public transportation.

And Europe remains a leader in the automotive sector,[b] where major carmakers and well-funded start-ups are driving a shift toward electric propulsion and self-driving systems. In Sweden, for example, Northvolt has broken ground on a $4.2 billion factory to produce lithium ion batteries for electric cars.

Indeed, European policymakers reckon batteries will be as essential to the automotive industry of the 21st century as the combustion engine was in the 20th century. The European Commission (EC), the European Investment Bank, and over 260 industrial and innovation stakeholders have joined the European Battery Alliance (EBA), which is now building its first pilot production facilities. The EC estimates Europe will need at least 20 'gigafactories' (large-scale battery cell production facilities) to meet local demand.

Building a CERN for AI

But maintaining its industrial and manufacturing base may require Europe to raise its game in AI and robotics, which promise to drive another industrial revolution. To that end, leading European scientists are trying to establish the European Lab

a The European Commission, Science, Research and Innovation Performance of the EU (SRIP) report: http://bit.ly/2DsKasE

b The European Automotive Manufacturers Association reports that the EU automobile and parts sector invested €53.8 billion in R&D in 2017, compared with €29.8 billion in Japan and €18.5 billion in the U.S; http://bit.ly/2DsKtUk for Learning and Intelligent Systems (ELLIS), a multinational institute that would be devoted to AI research. The concept is modeled on CERN, the particle physics lab created after the World War II to stem the flow of physicists across the Atlantic. Although it is not clear whether ELLIS will get off the drawing board, the EC has promised to spend an additional $1.7 billion on AI research between 2018 and 2020, which it hopes will stimulate a further $2.8 billion investment by public-private partnerships.

That comes on top of a pledge by the EC and EU members states to spend $1.1 billion building world-class supercomputers, after recognizing that Europe is also falling behind in this area. "We do not have any supercomputers in the world's top 10," Andrus Ansip, EC Vice-President for the Digital Single Market, said in January 2017. "We want to give European researchers and companies world-leading supercomputer capacity by 2020—to develop technologies such as artificial intelligence and build the future's everyday applications in areas like health, security or engineering." However, both China and the U.S. are also investing heavily in AI research and supercomputing capacity.

Commercializing Quantum Computing and 5G

The EC is also anxious for Europe to commercialize quantum computing. Blogging about its new $1.1 billion Quantum Flagship initiative, Ansip wrote: "While Europe has many world-class scientists in this field, there is so far little industrial take-up or commercial exploitation here." After the Graphene Flagship and the Human Brain Project, the Quantum Flagship is the third large-scale research and innovation initiative of this kind funded by the EC.

At the same time, Europe wants to lead the development and deployment of 5G wireless technologies. In 2018, the non-profit European Investment Bank has lent $580 million to Nokia and $300 million to Ericsson to further R&D related to 5G. To help build a global consensus on future 5G standards and spectrum requirements, the European Commission has established Joint Declarations on 5G with Brazil, China, Japan, and South Korea. Cooperation agreements are also being discussed with India and the U.S.

Trailblazing on Global Collaboration and Regulation

With 50 countries packed into one continent, Europeans are well accustomed to international collaboration, as evident in its major strategic alliances, such as Airbus, CERN, the European Molecular Biology Lab, and the European Space Agency, which are all backed by multiple countries within Europe. European businesses also tend to be supportive of international standards: Europe was the birthplace of GSM, the technology that brought mobile communications to the world.

Furthermore, Europe's regulators are highly influential. EU directives and regulations often form the basis for government interventions in other markets. The General Data Protection Regulation (see Laurence Kalman's article on p. 38) and the second Payment Services Directive, which both came into force in 2018, provide consumers with sweeping new rights to protect and extract their personal data. This radical legislation, together with the multibillion-dollar fines levied on Google, underlines the EU's readiness to try and exert more control over disruptive digital players from outside its borders.

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Consumers | DOI:10.1145/3309921

Europe's Well-Connected Consumers

BY DAVID PRINGLE

HOME TO APPROXIMATELY 740 million people, many of them affluent, Europe spends a lot of money on information and communications technology (ICT). The European ICT market was worth $769 billion in 2017 (up 1.8% from 2016).[a]

Yet, despite the best efforts of the European Union (EU), Europe is not one market. There are major cultural differences and economic disparities between northwest Europe and southeast Europe. Whereas Germany, the U.K., the Nordics, and the Netherlands tend to attract migrants from all over the world, many countries on the eastern and southern rims of Europe are seeing an exodus of young people and low birth rates. Indeed, the continent as a whole is aging: One fifth of the people in the 28 members of the EU (the EU28) are now 65 or over, compared with 17% in 2007.[b] In the U.S., the equivalent figure is 15% and in China 11%.[c]

The vast majority of Europeans are online. It is relatively cost-effective for the region's telecoms companies to provide connectivity: Europe is densely populated and heavily urbanized—three quarters of the EU population lives in cities, towns, or suburbs. Across the EU28, more than 87% of households had Internet access and 85% broadband Internet access at the end of 2017.[d] Moreover, the broadband is relatively quick: Of the top 50 countries ranked by broadband speeds worldwide, 36 of them are in Europe.[e] Sweden has the fastest broadband in Europe, offering an average

a The European IT Observatory; http://bit.ly/2FGV2FQ

b Eurostat; http://bit.ly/2TaeXQs

c The World Bank: https://data.worldbank.org/indicator/SP.POP.65UP.TO.ZS

d Eurostat; http://bit.ly/2sHEpB8

e Comparison website cable.co.uk; http://bit.ly/2DsPBYH speed of 46Mbps. However, interference between Wi-Fi networks is common in the many districts where people live in apartment buildings, while cellular networks can also be heavily congested in city centers.

Most Europeans now have smartphones. Approximately two-thirds of people in the EU28 between ages 16 and 74 had mobile Internet access at the end of 2017, up from 36% in 2012. But there are wide regional variations, with that figure reaching 87% in the Netherlands and Sweden, compared with just 32% in Italy and 40% in Poland. In 2017, close to three quarters (72%) of individuals in the EU28 accessed the Internet on a daily basis, with a further 8% using it at least once a week.

A Battleground for North American and East Asian Technologies

Lacking a major computing industry of its own, Europe is a relatively neutral market for hardware and software made in both North U.S. and East Asia. Major American and Asian brands go head-to-head in the smartphone, tablet, and computing markets, but their operating systems all hail from the U.S. Android dominates the European smartphone market. Some 70% of smartphones in use in Europe run Android, while 28% run Apple's iOS, while less than 1% run Windows.[f] However, in the tablet market, iOS has a market share of 66%, while Android has 34%. But there is one key smartphone component that hails from Europe—U.K.-based ARM Holdings' microprocessor architecture is used in more than 90% of the world's handsets. This low-power architecture has proven pivotal in the development of advanced handsets with long battery lives.

Social networking in many European countries is not as prevalent or as popular as in North America, the birthplace of Facebook and other leading social networks. Just over half (54 %) of Europeans age 16 to 74 use the Internet for social networking, while in France and Italy that proportion is as low as 43%,[g] potentially reflecting a preference for face-to-face interactions. In the same demographic, 57% of Europeans shop online, while 18% are using accommodation-sharing services, such as Airbnb, and 8% use

f Statcounter; http://gs.statcounter.com/os-market-share/mobile/europe
g Eurostat (figures for end of 2017); http://bit.ly/2sHEpB8

IMAGE BY RADIOKAFKA/SHUTTERSTOCK.COM

> **Europeans tend to be greener than North Americans. More than nine in 10 respondents (94%) say that protecting the environment is important to them personally.**

ride-sharing services, such as Uber.

In Europe's three largest economies (France, Germany, and the U.K) YouTube and Netflix are the top video streaming apps, ahead of local media players, while WhatsApp Messenger, Facebook, and Facebook Messenger are the top three social apps in these markets.[h] Although major U.S. Internet services are widely used across Europe, some smaller players also have significant traction. For example, London-based music recognition service Shazam, which was recently acquired by Apple, is ranked sixth in Italy in terms of monthly active users, and seventh in France, and ninth in Spain. In Russia, a market apart, cultural and regulatory factors have helped several local players, including Yandex, Mail.Ru, and Sberbank, compete very effectively with the global players. All of these have apps in Russia's top 10, as ranked by monthly active users.

Europeans Care about Privacy and the Environment

Privacy is a big deal for Europeans, particularly in Germany, which is very wary of state surveillance after the country's experience of authoritarianism in the first half of the 20th century: Some 45% of Europeans who use the Internet have installed or changed their antivirus software in the past three years due to privacy and security issues, while 39% say they are now less likely to share personal information on websites.[i] More than six in 10 respondents (61%) say the security and privacy features of an IT product play some role in their choice, while 27% are ready to pay more for better security and privacy features.

Europeans also tend to be greener than North Americans. More than nine in 10 respondents (94%) say that protecting the environment is important to them personally, and among these more than half (56%) say it is very important.[j] These findings have remained broadly consistent over the past decade.

Europeans have mixed feelings about the direction in which ICT is headed. Although more than six in 10 respondents have a positive view of robots and artificial intelligence, an even higher proportion (72%) agree robots and AI steal jobs.

h App Annie; https://www.appannie.com

i Eurobarometer; http://bit.ly/2FPIlb0
j Eurobarometer; http://bit.ly/2RIC47V

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GDPR | DOI:10.1145/3310326

New European Data Privacy and Cyber Security Laws—One Year Later

BY LAURENCE KALMAN

THIS HAS BEEN a momentous year for data protection and information security regulation in Europe, with two landmark pieces of legislation taking effect. Together they represent a major shift in the European industry's approach to privacy and security compliance.

The long-awaited General Data Protection Regulation (GDPR) came into force in the European Union (EU) on May 25, 2018, attracting a huge amount of attention and prompting a flurry of email messages to customers on historic marketing lists.

Now organizations that process personal data are regulated not only if they are established in the EU, but if they target goods or services at, or monitor the behavior of, individuals in the EU—regardless of where they are located. Service providers that process personal data for others become directly regulated, while individuals' rights to manage their data have been enhanced. And the new sanctions regime has given regulators real teeth, with the ability to levy fines up to the greater of €20 million or 4% of total worldwide annual turnover.

Shortly before the GDPR took effect, the deadline for EU member states to implement the Network and Information Security Directive (NISD) passed much more quietly. Often viewed as the GDPR's 'younger sibling,' the NISD has proven a less eye-catching piece of legislation although it too threatens hefty penalties for breach.

Whereas the GDPR focuses on protecting individuals' rights to privacy, the NISD originates in national security concerns. It aims to raise levels of cyber security in specific sectors that represent 'critical national infrastructure,' such as energy, transport, health and water, as well as among suppliers of essential digital services.

Many view Europe's approach to data privacy and cyber security as setting a global gold standard.

A New Culture of Compliance?

The GDPR has pushed data privacy compliance up the corporate agenda for the long term. Organizations must understand and document the personal data they use in far greater detail than before. Shortly before the compliance deadline, the International Association of Privacy Professionals and Ernst and Young estimated that large British firms had spent $1.1 billion on GDPR preparations, while U.S.-based companies had invested $7.8 billion.

According to research into GDPR readiness costs among FTSE100 companies carried out by management

IMAGE BY PAOPANO

consultants Sia Partners, banks were the biggest spenders at over £60 million on average. Next came the energy, commodities and utilities, retail goods, and technology and telecommunications sectors, with an average implementation expenditure of approximately £15–£19 million per company. And ongoing obligations under the GDPR will create a lasting increase in compliance costs across sectors.

Compliance also plays a major role under the NISD. The regulatory burden represents a greater shock to the system for industries that have not previously been required to prioritize cyber security or incident reporting. Organizations are also spreading the NISD compliance burden along their supply chains into sectors that are not directly regulated. One beneficiary of the increase in compliance risk is the insurance sector, and both the NISD and GDPR will continue stimulating the cyber insurance industry.

Growing Consumer Awareness

The GDPR in particular has had a noticeable effect on improving individuals' awareness of, and assertiveness in exercising, their data privacy rights. Organizations that hold large volumes of customer data have received rising numbers of data subject access requests, which can be costly to comply with.

Greater consumer awareness is also evident in increasing levels of interaction with regulators. In the first few months after the GDPR came into effect, the French regulator reported a 64% increase in complaints from individuals, which in its view showed that EU citizens had warmly embraced the regulation.

Alongside the introduction of the GDPR and NISD, the European Commission has emphasized that building a European data economy is a key part of its 'digital single market' strategy.

But there is a natural tension between the desire to protect data privacy, boost cyber security, and promote a burgeoning European economy based on free-flowing data. It remains to be seen whether a data-driven economy can continue to flourish once the new regulations really start to bite.

In this more hostile environment, businesses and regulators will need to work hard to avoid a situation where Europe becomes a less attractive region to test and roll out new products. Balancing the free flow of data with respect for privacy and security concerns will be essential to the success of a dynamic, connected European economy.

On the other hand, many view Europe's approach to data privacy and cyber security as setting a global gold standard. Numerous countries still have no coherent data protection laws in place at all. Only a select few—Andorra, Argentina, Canada, the Faroe Islands, Guernsey, Israel, the Isle of Man, Jersey, New Zealand, Switzerland, Uruguay, and the U.S. (only under the Privacy Shield framework)—have data protection laws that reach the required threshold to be considered adequate by the EU. China is moving toward stringent data protection standards but still has a patchwork of regulation in place.

There is a natural tension between the desire to protect data privacy, boost cyber security, and promote a burgeoning European economy.

There are also signs that U.S. consumers look longingly at the protections available in the EU. According to a survey conducted in April 2018 by Janrain, the customer profile and identity management software provider, 68% of respondents wanted a GDPR-like law in the U.S. Some 38% identified their top priority as the ability to control how their data is used, while 39% focused on the right to require organizations to delete their data.

When Will the Other Shoe Drop?

The U.K. Information Commissioner's Office (ICO) issued its first formal GDPR notice in July 2018. This required data analytics firm AggregateIQ to stop processing data relating to U.K. individuals that it held through its work for the 'Leave' campaign in the EU membership referendum, and that it continued to process in breach of the GDPR. Following an appeal, the ICO narrowed its enforcement notice and no fine has been issued.

One of the first GDPR fines was issued by the Portuguese regulator against the Centro Hospitalar Barreiro Montijo in July 2018. A fine of €400,000 was levied against the hospital for two GDPR breaches relating to unauthorized access to patients' data and inadequate data security—still a relatively modest amount in contrast to the maximum available. In January 2019, the French regulator raised the stakes by issuing a record €50m fine against Google, due to insufficient transparency, inadequate information, and a lack of valid consent in relation to personalized advertisements.

The full impact of the GDPR and NISD will therefore become clearer as regulators flex their muscles and issue more large-scale fines. Although we have not yet witnessed the predicted rush of group litigation, an uptick in data protection-related class actions is also likely.

The GDPR and the NISD are still in their relative infancy, but they will be with us for a long time to come. Generating trust will be the key to success in this increasingly connected world. Organizations must show they take cyber security and data privacy concerns sufficiently seriously to win consumers' confidence. Doing this while also providing market-leading services will enable Europe's data-driven economy to succeed in the years to come. C

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Research | DOI:10.1145/3310328

Incorporating Europe's Values in Future Research

BY JAN GULLIKSEN

OUR SOCIETY IS currently undergoing several big changes that pose challenges and opportunities for the future. The increasing digitalization and automation, the growing globalization, and improved financial durability offer many excellent opportunities for development. There is more research funding in the system than ever before. On the other hand, our society is vulnerable; we have challenges in relation to inequality, an environment put under severe stress, and more hostile tendencies than we have seen in a long time, despite the good times and economic growth. In our work at the European Commission Independent High Level Group on Maximizing the Impact of EU Research & Innovation Programmes,[4] we try to understand and elaborate on these challenges to be able to propose a suitable strategy for future research funding from the European Commission.

With an area of 10 million square kilometers and a population of 740 million, Europe is a substantial region of prosperity and development. Many EU countries lead in rankings of prosperity, education, digitalization, equality, and low corruption.

Investment in research and innovation has been substantial and recognized as important for the development of the society, for ensuring a high level of skills, and for contributing to the creation of jobs and growth, albeit not to the extent demonstrated by North America or South East Asia. With just 7% of the world's population and 24% of global GDP, the EU produces approximately 30% of the world's scientific publications.[4] Several European

I foresee a time when learning is a lifelong commitment, with people spending 10%–20% of their work time continuing their education in order to learn new skills and make oneself relevant as the future unfolds.

countries are leading the research investment competition as a share of the country's GDP—after the three top countries Israel, Korea, and Japan—with Europe at 2.03% and Sweden leading in Europe with investments of 3.26% of the GDP.[a] In the Lamy report,[4] we argued for a European target of 3%.

However, the business economy in high-tech sectors and PCT patent applications per-million population both show a lower growth rate in Europe than in U.S. Hence, Europe must focus on innovation and investigate the mechanisms within its society that prevent development on a scale the same as the U.S.

The EU funding program Horizon 2020 that focuses on scientific impact was prioritized particularly through the ERC program for funding excellent basic research. This turned Europe into an attractive arena to develop research careers and thus strengthening European research quality and performance.

Trends and Needs for Future European Research

Some of the most prevalent trends and needs that may influence future research and innovation throughout Europe include the following:

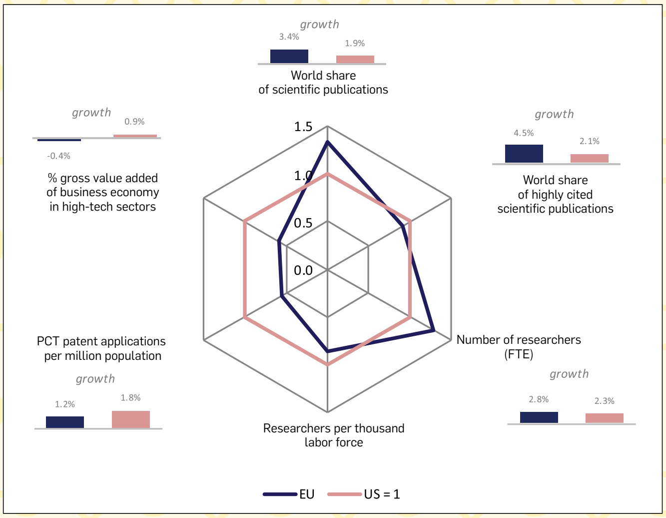
- *Societal challenges of importance and acuteness.* The EC has conducted activities to foster mission-driven science and innovation based on the activities by Maz-

a UNESCO Institute for Statistics; http://bit.ly/2R7q2jg zucato[5] to target the overall goals of research to address the forefront of development. Horizon 2020 aims for challenges, while Horizon Europe seems to focus more toward missions. A possible mission agreed by many is to join forces to achieve the Sustainability Development Goals.[9]

▸ *Increasingly complex research problems.* The challenges on today's research agenda are becoming bigger and more complex, requiring large multidisciplinary collaboration teams. While traditional research strives to limit and focus research questions to problems that could derive scientific conclusions beyond any doubt, today's problems are becoming increasingly more "wicked,"[7] without the opportunity to isolate particular phenomena for empirical testing. To research such problems requires methodologies and processes to develop knowledge under these conditions, ensuring scientific rigor, quality, and ethical standards being met.

▸ *Multidisciplinarity opportunities and challenges.* Today's complex problems require a more genuine and open collaboration across a wide range of different disciplines. It requires each individual builds a broad understanding of the context of research far beyond the disciplinary research agenda in addition to the depth required within their own field.[1] It requires true transdisciplinary work, including social science and humanities (SSH) from the outset, to be able to tackle complex problems in technical and medical research and innovation in a meaningful way.

▸ *Unprecedented technological development.* The last decades of development has



Comparative and growth rates of scientific publications, highly cited scientific publications, researchers, patent applications and valued-added of high-tech sectors in the EU compared to the U.S.

SOURCE: EUROPEAN COMMISSION, DG RESEARCH AND INNOVATION. DATA: EUROSTAT, OECD, CWTS BASED ON WEB OF SCIENCE DATABASE.[4]

seen the birth and growth of many groundbreaking innovations that changed our everyday lives. Advancements have had an impact not only on the technology itself, but also on disciplines such as medicine, SSH, economy, and basic science. There is no reason to think development will slow down, rather we must embrace and support the development and maintain high ethical standards in the development.

▸ *Innovation.* One of the major political arguments for investing in research is that it will eventually lead to the development of new products, services, or knowledge with the potential to create new companies, employment opportunities, and eventually contribute to the economic growth of the society. The mechanisms for supporting more disruptive innovation is essential.[10]

▸ *End-user involvement and citizen science.* An essential characterizing aspect of future research and innovation is the need to incorporate and involve the general public to a much larger extent and engage in so-called citizen science.[2] People may become involved as participants, for example, in more action-oriented research projects sharing their personal data.[3] To be able to address our future challenges, they will become reflective practitioners[8] in the analysis and reconstruction of the society.

▸ *Connection to education.* Digitalization means changing the ways we educate by providing opportunities to offer education to everybody. I foresee a time when learning is a lifelong commitment, with people spending 10%–20% of their work time continuing their education in order to learn new skills and make oneself relevant as the future unfolds. These needs must be addressed when building the research community, as there is a tight and important connection between research and education.

▸ *Research leadership.* There is a need for leadership that understands transdisciplinary research and knows how best to engage participants. Trustworthy and engaging leaders can guide teams through complex, wicked problem solving.

A value-driven research process, recognizing the European values of participation, gender equality, and low corruption has been powerful throughout Europe. The key factors in reducing inequality include a strong focus on education, health, social protection, progressive taxation, higher wages for the general workforce, stronger labor rights, especially for women.[6] These values makes Europe a unique place to develop research that features strong human and humanistic values, a strong commitment to the U.N. sustainability goals, and recognizing the opportunity for overall participation on equal terms beyond hierarchies, knowledge levels, education, or assets. ■

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Networking | DOI:10.1145/3310324

HiPEAC: A European Network Built to Last

BY KOEN DE BOSSCHERE, MARC DURANTON, AND MADELEINE GRAY

HIGH PERFORMANCE AND Embedded Architecture and Compilation (HiPEAC) was founded in 2004 as a European research network. In the last 15 years, it has grown from 70 to 2,000 computing specialists, including 200 from industry, making it the largest such network in the world. Membership is free, but members are expected to be active participants in the network.

Today, HiPEAC is a hub for European researchers and industry representatives in the full range of computing systems (from sensor nodes to exascale systems).[a] It has received uninterrupted funding from the European Commission for helping to implement Europe's policy to strengthen the computing community throughout the region.[b]

a https://www.hipeac.net/
b HiPEAC is funded by the European Commission under grant agreement 779656.

The HiPEAC staff hosts a one-week summer school program for computer architects and tool builders working in the field of high-performance computer architecture and compilation for computing systems.

The HiPEAC Conference is the second largest European research gathering in computing and it is the flagship event of the network. It pioneered the innovative journal-first publication model, which means ACM's *Transactions on Architecture and Code Optimization* (TACO) evaluates and published papers submitted for the HiPEAC Conference and authors of accepted papers receive an invitation to present their work at the conference. This year, all papers published in ACM TACO will be open access, which follows the requirement that all published work resulting from European-funded research programs must be open access. By combining the conference with a rich program of workshops, tutorials, poster sessions, and an industry exhibition, the HiPEAC Conference has become the premier networking event for the European computing community.[c]

The HiPEAC conference has become the premier networking event for the European computing community.

The ACACES summer school is another major event hosted by HiPEAC, attracting more than 200 attendees from academia and industry for a full week of advanced courses taught by world-class experts. Many attendees have credited ACACES as a life-changing event at the start of their career.

Since 2012, HiPEAC has actively invested in attracting and retaining talent in Europe. The network's careers services, in combination with its jobs and internship portal,[d] support HiPEAC members in their

c https://www.hipeac.net/events
d https://www.hipeac.net/jobs/

ALL IMAGES COURTESY OF HIPEAC

search for skilled talent, or to land the perfect job in Europe. In particular, we try to match around 200 Ph.D. students yearly with the many open computing positions throughout Europe.

HiPEAC Vision, an influential biennial roadmap report produced by the community, contains a detailed SWOT-analysis of the European computing industry, including trends in the market, society, and in science and technology and provides a series of recommendations to strengthen Europe's position in the field. It is one of the key inputs in defining future research programs at the European level.[e]

Lessons Learned

HiPEAC's impact in Europe's computing community takes many paths. Beyond the services it provides members, it also fosters more international collaboration, a larger supporting network, and has lessened the region's brain drain. For example: HiPEAC has distributed approximately 400 mobility grants, which have led to numerous scientific collaborations as well as the creation of start-ups and permanent hires. The HiPEAC jobs portal publishes over 500 career opportunities per year. Over 200 scientific projects have used the HiPEAC platform for promotion, of which 50 are HiPEAC stakeholder members. The network also functions as an effective bidirectional communication channel between European policy makers and the European research community at large.

It took HiPEAC about 10 years to create a strong and attractive brand, to build a large and vibrant community, and to discover the services the community valued most. HiPEAC's decision to hire a dedicated, professional staff to run the network rather than rely solely on volunteers was a turning point. Building an effective international network requires time, resources, vision, and perseverance. It simply cannot be done in a couple of years, it is difficult to accomplish with only volunteers, and it cannot survive without funding.

It took HiPEAC about 10 years to create a strong and attractive brand, to build a large and vibrant community, and to discover the services the community valued most.

Europe is neither the U.S. nor China. It takes its own approach to building a robust, innovating computing community, one that fits the European strengths, and provides answers to European challenges and European ways of thinking. In addition to investing in technology areas like artificial intelligence, cyber security and cyber-physical systems, Europe should also invest in its small and medium-sized enterprises, which form the backbone of its economy. For example, finding solutions for societal challenges such as the rapidly ageing population by developing the "silver economy" and investing in healthcare technologies, or focusing on its low economic growth by promoting industry 4.0; or facing environmental issues by addressing the United Nation's sustainable development goals. Europe should also invest in retraining programs for workers and in improving the digital skills of the global population.

e https://www.hipeac.net/vision

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A presentation session during HiPEAC 18 in Manchester, U.K.

Attendees of HiPEAC 17 congregate at the Waterfront Congress Centre in Stockholm, Sweden.

Recognition | DOI:10.1145/3309952

ACM Europe Council's Best Paper Awards

BY JOAQUIM JORGE, MASHHUDA GLENCROSS, AND AARON QUIGLEY

THE ACM EUROPE Council's remit is to support European ACM members while increasing the level and global visibility of ACM activities throughout Europe. Toward this goal, the ACM Europe Council's Best Paper Awards aim to achieve three key objectives: First, is to foster, recognize, and reward research excellence showcased at ACM-sponsored conferences held in Europe. Second, is to expand awareness of the many high-quality, ACM-sponsored events that take place annually within Europe. Third, is to enhance diversity and inclusion of European research across the global ACM community of researchers, students, and practitioners.

The ACM Europe Council's Best Paper Awards recognize authors of outstanding technical contributions to ACM-sponsored conferences held in Europe. In addition, these awards acknowledge groundbreaking research in each conference's discipline for its importance and contribution to computing, and to highlight theoretical and practical innovations likely to shape the future of computing both within Europe and globally. This initiative began in 2016 as an award to recognize best student papers. In 2018, the ACM Awards Committee recognized the initiative as a meritorious endeavor that now extends to both junior and senior participation categories. Thus far, eight awards have been bestowed, and six more are planned for the fiscal year 2019 including ACM CHI19 in Glasgow. Currently, this is the only regional-based best paper award of its kind offered by ACM.

Xiao Han receives the ACM Europe Council Best Student Paper Award from Gabriele Anderst-Kotsis during CCS 2016 in Vienna, Austria.

The ACM Europe Council's Best Paper Awards recognize authors of outstanding technical contributions to ACM-sponsored conferences held in Europe.

There are between 30 and 50 ACM-sponsored conferences held annually in Europe. These events bring together a community of 6,000–10,000 researchers, students, and professionals. While every ACM-sponsored conference that takes place in Europe is eligible for the award, to date only a few have been invited to confer this distinction. Among those, for example, is the ACM Conference on Computer and Communications Security (CCS, the flagship annual conference of ACM's Special Interest Group on Security, Audit and Control or SIGSAC), which bestowed this award in 2016. From its inception, CCS has established itself as a high standard research conference in its area. The ACM Europe Council was proud to join SIGSAC in awarding the Best Student Paper to Xiao Han, Nizar Kheir (Orange Labs), and Davide Balzarotti (Eurecom) for their work "PhishEye: Live

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Monitoring of Sandboxed Phishing Kits."[a]

Another well-established venue is ACM Virtual Reality Software Technology, one of the oldest conferences in the field of virtual reality. The ACM Europe Council was proud to join SIGCHI/SIGGRAPH in bestowing the Best Paper Award to Misha Sra, a student from MIT's Media Lab Student, Sergio Garrido-Jurado, from the University of Córdoba, Chris Schmandt, and Pattie Maes from MIT's Media Lab for their paper entitled, "Procedurally Generated Virtual Reality from 3D Reconstructed Physical Space."[b] This award aims to foster excellence, and as recipients Garrido-Jurado and Sra commented: "The award was a validation of an idea we both strongly believed in despite some people telling us otherwise."

The ACM Europe Council was also honored to bestow on researcher Sergio Cabello, his first Best Paper Award in recognition of his work, "Subquadratic Algorithms for the Diameter and the Sum of Pairwise Distances in Planar Graphs," at the ACM-SIAM 2017 Symposium on Discrete Algorithms. This distinction aims to expand awareness of ACM conferences held in Europe, and as Cabello noted, "I definitely got a lot of recognition from colleagues in my research area because of the award."

For most of its recipients, the ACM Europe Council's Best Paper Award was their first such distinction. It will be interesting to see what lasting impact this recognition will have on the awardees. From their initial feedback, the short-term personal impacts have ranged from "more recognition from colleagues," "more speaker invitations," "more requests to review papers," "wider recognition for authors within their institutions and internationally," "confidence to continue to work on projects," "a first step of a European funded project," "follow-on journal papers," and "encouragement and validation." By showcasing such work, and underscoring the diversity of research areas represented at ACM-sponsored conferences held across Europe, this award will continue to highlight excellence to the global ACM community.

For more details about the award, and to view distinguished papers to date, visit https://europe.acm.org/awards.

a https://dl.acm.org/citation.cfm?id=2978330
b https://dl.acm.org/citation.cfm?id=2993372

By showcasing such work, and underscoring the diversity of research areas represented at ACM-sponsored conferences held across Europe, this award highlights excellence to the global ACM community.

Misha Sra receives the ACM Europe Council Best Student Paper Award from Hans-Joachim Hof during VRST 2016 in Munich, Germany.

Joaquim Jorge is a professor of computer graphics and multimedia at the Departamento de Engenharia Informática do Instituto Superior Técnico da Universidade de Lisboa in Lisbon, Portugal. He is also secretary of ACM Europe Council.

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Aaron Quigley is chair of Human Computer Interactions at the University of St. Andrews, Scotland. He is SIGCHI vice president for conferences and general co-chair for ACM CHI 2021.

ACM Europe Council seeks to continue its engagement with ACM conferences held in Europe. If you are chairing such a conference and would like to be considered for the ACM Europe Council's Best Paper Award, please contact jorgej@acm.org.

big trends

DOI:10.1145/3312563

BY JULIE A. MCCANN, GIAN PIETRO PICCO, ALEX GLUHAK, KARL HENRIK JOHANSSON, MARTIN TÖRNGREN, AND LAILA GIDE

Connected Things Connecting Europe

IT IS ESTIMATED that personal computers, datacenters, and other technologies constitute less than 1% of all microprocessor usage;[10] embedded systems represent the remaining percentage and can be found in our washing machines, microwaves, remote controls, and PC peripherals (such as keyboards and mobile phones), with modern cars containing many tens of embedded microcontrollers.[18] Modern embedded-system microcontroller and transceiver technology advancements have brought forth the kinds of systems we have in the past defined as pervasive, ubiquitous, and embedded computing, and for some time in Europe, "embedded intelligence." However, today they are better known as the Internet of Things (IoT) and cyber-physical systems (CPS); see the figure here.

The jury is still out regarding a definition of the latter two terms or indeed how to differentiate them, but people generally tend to refer to IoT as embedded devices that connect to the Internet to exchange data, optimize processes, monitor environments, and typically consist of sensors, actuators, and low-power compute infrastructures. CPS is a term first coined in 2006 in the U.S. to characterize "the integration of physical systems and processes with networked computing" for systems that "use computations and communication deeply embedded in and interacting with physical processes to add new capabilities to physical systems."[22] CPS is generally put forward as the more systems notion, while IoT emphasizes communication and analytics, yet IoT-like devices need not always use Internet protocols to create a CPS, hence the ambiguity. The European Commission debated for two years whether to call its embedded intelligence programs CPS, with the latter winning out in the end. In this article, we embrace these terms fluidly and name them IoT/CPS; for other definitions, see the sidebar "Some Definitions."

In essence, the terms represent different perspectives on the technological advancements that have led to creation of many related application terms—industry 4.0, smart cities, preci-

IMAGE BY GARRY KILLIAN

sion agriculture, smart transport, and autonomous vehicles—all representing new classes of technologically enabled systems. Recent studies have predicted the impact of IoT/CPS on the European Union's GDP in 2025 by sector, with "transportation" being forecast to create the greatest value, with a total of €245 billion alone, followed closely by "healthcare," "housing," and "industry."[1] As in the rest of the world, European countries and the European Commission have invested heavily in IoT/CPS research, almost €200 million, resulting in many cross-discipline, cross-country technology advancements unique in terms of their focus on the integration of such systems, particularly at scale, their underpinning communications substrates, and, more recently, their security and relationship to privacy. In this article we describe highlights of this work in more detail and present what we believe are the main outstanding challenges facing the field for Europe over the next decade.

The Integrated Approach

Two decades ago, a European named Kevin Ashton coined the phrase the "Internet of Things." His vision of connecting sensor- and actuator-based technology to the Internet unfolded an active area of technological advancement around the world that only in the past few years has begun to find larger-scale adoption and is finally becoming a commercial reality. In parallel, the University of California, Berkeley's TinyOS and Mote hardware combination dominated early academic experimental work on wireless sensor networks, also making its way into various commercial products. While the U.S. focused on designing new protocols and approaches to overcome the intrinsic limitations of resource-constraint IoT/CPS devices, the focus in Europe was more on the integration of such systems to fulfil real application needs. In particular, tools to aid the building of devices and, moreover, their applications became the European emphasis, resulting in mechanisms to ease programming and systems engineering and, more important, make such systems a natural extension of the Internet, the latter reaping the advantages of standardization and the software-engineering experience that programmers already had from other Internet systems.

Adam Dunkels of SICS in Sweden developed the Contiki operating system that has significantly grown in popularity, particularly over the past decade. As the technology matured, device hardware could pack more compute power for the same energy budget, and the resource savings TinyOS delivered thus became less important. Exploiting this power, Contiki's advantage over its predecessors lay in its flexibility and ease of coding applications. Indeed, today hackers, academic institutions, and companies are using Contiki because it remains lightweight, mature, and free; for example, Texas Instruments (a U.S. company) ships many of its IoT/CPS devices (such as Sensortag) with the option of using Contiki.

At that time, the prevalent communications protocols operated over low-data-rate, local-area networking (up to approximately 50-meter distances) radio transmissions. 802.15.4-based protocols (such as ZigBee, designed in the U.S.) overcome these short distances by providing multi-hop communications, allowing data to be relayed between devices to form longer-distance routes and hopping the data from device to device. However, in Europe, for researchers (such as Dunkels), the quest was now to push the Internet Protocol all the way down to small embedded devices themselves.[2] Early attempts include the work of Zach Shelby, an American, working at Oulu University,[3] but the now-ubiquitous 6LowPAN protocol has emerged to provide lightweight end-to-end Internet connectivity down to the smallest devices and has gradually replaced the previously popular ZigBee communications approach.

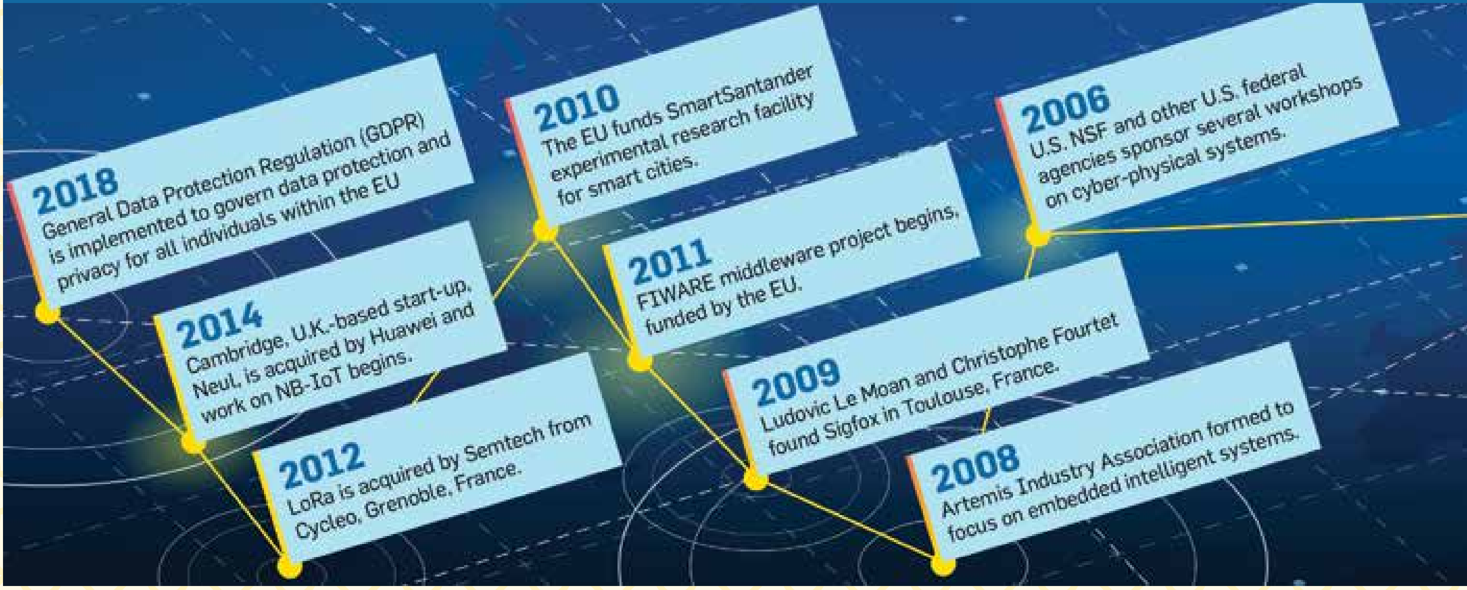
While 6LowPAN allowed for more efficient raw Internet communication, the next logical step was to make it Web friendly by replacing its heavy Web protocol with a more lightweight one. Work emanating from European large-scale mixed academic/industrial projects (such as SENSEI and FP7) focused on how such emerging wireless sensor and actuator networks can be more effectively integrated into a future Internet.[4] Shelby worked with the Internet Engineering Task Force (IETF) and such companies as England's ARM low-power processor design company, ultimately producing the COAP protocol[5] used to make applications on low-power devices easier to program. At about the same time, Dom Guinard at ETH Zurich and others advocated for such devices to become first-class citizens in the current Web. His pioneering work led to what is now known as the Web of Things, with active work (as part of W3C) receiving support from Siemens, Google, and other sources.[6]

The increasing investment in CPS/IoT throughout Europe, and the world, has meant an increase in the number of systems, protocols, and applications being built. Also, there was little integration between systems, as seen especially in the smart-city domain. This fragmentation is thought to have undermined the confidence of stakeholders and market opportunities, affecting IoT adoption, thus causing Europe to become increasingly focused on the applications built on top of IoT/CPS systems and their integration.[7] Indeed the perception in Europe was that while U.S. IoT/CPS innovation focused on adoption environments based on individual business cases driven by economic return on investment, Europe's industry and academic researchers focused on the exploration of societal benefits and acceptance of CPS/IoT technology generally.

One major success resulting from the European joint research and industrial projects is FIWARE, a curated framework of open source-platform, market-ready components to accelerate development of IoT/CPS systems and their integration with cloud services.[8] Since its beginnings in 2012, FIWARE has evolved from a consortium of multinational telcos, including Telefónica (Spain), Orange (formally French Telecom), and others, to a suite of more than 50 components to create value from real-world applications enabled by the ubiquity of heterogeneous and resource-constrained devices. Another example is from the ARTEMIS Industry Association,[9] with more than 170 members and associates from all over Europe, and the European IoT Platform Initiative Programme (IoT EPI), a €50 million programme with nine projects involving more than 40 different IoT platforms exploring multiple approaches to interoperability.[11]

An example of where Europe leads in living-lab deployments is the SmartSantander testbed in Santander, Spain, a prominent European experimental infrastructure for IoT/CPS. By embedding a large number of diverse sensor devices into a city environment, it allowed a variety of smart city use cases to be explored. While initially useful for experiments with IoT protocols and data-driven services, the infrastructure is now part of the Santander's day-to-day operation, improving the lives of its citizens. Since its beginnings in 2010, more than 12,000 sensor devices have been deployed across the city to help the government operate as efficiently as possible through such applications as adaptive traffic management, smart parking, water management, intelligent streetlights, and waste disposal. SmartSantander went on to inspire other initiatives around the world, in-

Timeline of some key IoT events.



cluding the Array of Things project in Chicago.

Both testbeds and living labs[21] paved the way for IoT large-scale pilots in Europe, a €100M R&I program that commenced in 2017.[12] Examples of such projects include SynchroniCity (eight smart-city pilots[13]), MONICA (IoT technologies to manage sound and security at large, open-air cultural and sporting events[14]), and IoF2020 (Internet of Food and Farm 2020 with 70 partners from 16 European countries[15]); many of these projects are associated with, and continue to use, the FIWARE infrastructures.

Underpinning Communications Technologies

The communications substrate in an IoT/CPS architecture plays a crucial role, and low-power wireless connectivity is fundamental to balancing connectivity performance with low-power system capabilities and lifetimes. Freedom from power and data cables provides mobility and autonomy of devices that are readily deployed and relocated, can improve performance, and follow the users and objects they are attached to, or even move of their own volition, as with robots and drones. In recent decades, wireless communications was dominated by Wi-Fi and cellular communications that were ubiquitous yet energy-hungry; low-power alternatives had to emerge, as embodied by ZigBee in 2004. Today, the wireless communication landscape is significantly more fluid, with several technologies (both competing and complementary) offering disruptive opportunities unthinkable only a few years ago. Interestingly, several of these trends are the result of achievements by European researchers and companies, as we highlight here.

A prominent example is a new class of communications mechanisms described as "low-power wide-area networks" (LPWANs) that recently revealed trade-offs in the amount of power they require from the device, geographic coverage or distances they send data, and data rates. Until a few years ago, long-range communication was a privilege of cellular telephone communication, where devices were fitted with SIM cards and communicated typically over 2G GPRS networks. This did not match with the low-power nature of CPS/IoT devices and meant they were required to be plugged into the mains, limiting where they could be placed or receive frequent battery changes, and many stakeholders were reluctant to rely solely on proprietary networks and devices owned by operators.

SigFox[16] based in France was in 2009 the first to use ultra-narrowband modulation to enable longer-distance communications while remaining low power. Since the first deployments that covered the entire country of France, SigFox showed its technology can provide coverage like cellphone communications but without the need for a SIM card and at significantly less cost in terms of money and energy. But SigFox is still a telco operator, having to manage access to its own network and based on proprietary technology. In contrast, LoRa,[17] which was developed by Cycleo of Grenoble, France, and acquired by Semtech in 2012, used radio technology based on chirp spread spectrum modulation to effect low-power wide-area transmission. The LoRa Alliance then defined a public suite of protocol specifications (LoRaWAN) that allows a telco operator to deploy its own networks but also enables deployment and operation of privately owned networks operating side-by-side. Both SigFox and LoRa have their main center of gravity in Europe; for instance, of the 5,000+ gateways deployed today, 3,000+ are in Europe. This is also reflected in the surge of competing, industry-driven approaches, among which, arguably the most prominent, is Huawei's NB-IoT. Indeed, today's version of NB-IoT, which is being specified by the 3GPP, an international body of telcos, originated in early work by NEUL, a company from Cambridge, U.K., that developed the Weightless protocol and was bought out in 2014 by Huawei. LPWA technologies are not being rolled out worldwide.

Where LPWA supports slow data over great distances, ultra-wideband (UWB) communications permits higher data volumes and speeds over short distances. Originally used for military applications, UWB became unlicensed in 2002, but a new wave of interest has followed a small Irish company called DecaWave[19] when it released the

Some Definitions

Microcontroller. Computer on a single chip, with one or more processor cores, memory, and input/output peripherals.

Sensor nodes/mode. Generic way to describe sensor-based devices, typically consisting of several sensors and radio communications module(s) governed by a microcontroller. Different from phones and traditional computers, they are a few centimeters in size without keyboard or screen. An example is the University of California, Berkeley, TMote Sky sensor node consisting of the CC2420 ZigBee near-range communications, an MSP430 low-power microcontroller packed into a matchbox-size form factor.

Actuator. A device that controls other devices (such as valves and switches).

European Research Council. A body that funds technological research in the EU. Its framework funding programs include FP7 (Framework Programme) finished in 2013, giving way to H2020 (Horizon 2020). On top of this, each EU country also has national funding infrastructures, as in EPSRC in the U.K. and DFG in Germany.

IETF. The IETF is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of Internet architecture and smooth operation of the Internet; for more, see https://www.ietf.org/about/

DW1000 chip, overcoming many of bulkiness and power-consumption issues and storming the field of real-time location-tracking systems. Indeed, the potential here is enormous, especially if UWB chips eventually find their way into smartphones where UWB could trigger a new wave of location-based IoT/CPS services with an impact comparable to (if not greater than) that achieved by GPS.

Trust, Safety, Security, Privacy (Guarantees)

CPS and IoT provide unprecedented capabilities and opportunities for the benefit of society. But it will be achieved through corresponding unprecedented technological complexity that also introduces new risks that need to be recognized, debated, and dealt with appropriately. This is essential since future CPS and IoT will be widespread and underpin a large number of critical societal infrastructures, including water, energy, transportation, and healthcare, all relying on the proper operation of the technologies.

A key concern is that current engineering methodologies are generally viewed as inadequate for next-generation CPS. Consequently, multiple calls have been issued from the EU for new methodologies, including Platform4CPs,[25] AENEAS,[26] and the Acatech National Academy of Science and Engineering.[27] The full potential of future CPS can be obtained only when new engineering methodologies are in place to ensure future CPS systems are sufficiently safe, secure, available, privacy-preserving, and overall trustworthy. A science for CPS engineering is needed. Europe is positioned well in this regard to address the key challenges of complexity management, safety, and security by design and privacy.

Complexity management of IoT/CPS systems is important because they inherit the complexity of their cyber and physical parts. There is a lack of approaches to systematically accomplish "composability" of CPS components, meaning achieving integration of CPS components is difficult without negative, sometimes unknown, side effects, or emerging behaviors.[28] Composability for CPS must address the multifaceted dependencies in CPS across components, functions, and system-level properties. An example of a European stronghold is the effort driven by Kopetz on composable time-triggered architectures, with research funded through several EU projects that have influenced many communication protocols for CPS, delivered reusable architectural services for exploitation across platforms of different domains (INDEXYS project in 2008), and paved the way for successful companies like TTTech.[20]

The use of machine learning, particularly deep learning, provides a novel technology within CPS. While such technologies enable entirely new types of applications, they raise concerns about how to deal with transparency (black-box behavior), robustness, predictability (such as when data is outside a training set), and how to cost-efficiently verify, validate, and assure such systems.[29,30] In addition, CPS systems must function in increasingly complex environments, as in automated driving. Describing such varying environments and systematically dealing with uncertainty represent further key challenges that have been addressed in such European research projects as Pegasus[31] and the U.K. EPSRC-funded S4: Science for Sensor Systems in 2016.[32]

Safety and security engineering concerns the connectivity and spread of CPS and provides new attack surfaces that could exploit vulnerabilities in the cyber and/or physical side, as well as among human stakeholders. This implies existing security approaches are not suitable. Moreover, security may affect safety, thus calling for integrated and balanced security and safety trade-offs and development of new methodologies. The widespread use of CPS systems and their increasing automation imply that existing safety-engineering approaches are not sufficient, and, in particular, that future CPS will need to deal with risk explicitly, incorporating measures of dynamic risk, as compared, again, with automated driving. An example of security research in Europe comes from the £23M PETRAS Research Hub in the U.K., which involves 60 projects researching the various aspects of IoT/CPS security, from devices to social practice, and have produced a landmark report, *The Internet of Things: Realising the Potential of a Trusted Smart World*,[33] co-produced with the Royal Academy of Engineering.

It is infeasible to predict all possible faults, threats, and failure modes for future CPS. Systems will have to be resilient, with built-in build monitors and error handlers to ensure cost-efficient dependability. Examples of European efforts include the MBAT project that gave European industry a leading-edge affordable and effective validation-and-verification technology in the form of a Reference Technology Platform (the MBAT RTP) and the AQUAS project, which is developing solutions for safety/security/performance co-engineering, as in Sillitto.[34] Europe has a strong tradition in dependability and engineering of trustworthy systems, notably through the ARTEMIS and ECSEL private-public partnerships. Example projects include Pegasus, funded by the German Federal Ministry for Economic Affairs and Energy and involving all major German OEMs and Tier 1 companies to produce mechanisms to test and formally verify autonomous vehicles. And SCOTT is examining frameworks to enable development of secure and connected trustworthy things primarily for the rail-transport industries.[35] Separately, the TrustLite security framework from the Intel Collaborative Research Institute for Secure Computing (a collaboration of TU Darmstadt, University of Helsinki, and other European security institutes) have produced an Execution-Aware Memory Protection Unit that provides programmable operating system-independent isolation of software modules at runtime for low-cost embedded devices.

IoT/CPS systems are constantly monitoring homes, factories, cars, and more, and while understanding these processes can make them more efficient, sustainable, and safe, they can expose privacy concerns. The most prominent European initiative affecting IoT/CPS data gathering is that of the General Data Protection Regulation (GDPR) regarding data protection for individuals in the EU and its economic area.[36] The European approach to privacy is that, through GDPR, all the requirements of data domains and territories are consolidated into a single coherent and well-defined regulation. One aspect of this is that a data owner must prove its data protection reasonably matches the current state of the art, which in turn uniquely drives practical anonymization research. Researchers aim to demonstrate privacy shortfalls to make schemes more robust. For example, U.K. and Belgium researchers[37] were able to prove it took only four location points to be able to uniquely identify someone 95% of the time and that data coarsening and noise addition do not help. This was followed by Gadotti et al.,[23] who showed privacy techniques using "sticky noise" could be easily infiltrated. All European citizens, as well as those only visiting Europe, are covered by GDPR, meaning its effect reaches much farther than just Europe.

Conclusion

We have drawn out three views of IoT/CPS systems the European approach to research contributes to in its own unique way, though European researchers continue to collaborate across the globe to address the many challenges associated with these systems. This subject continues to grow and, with it, new problems. For example, as such systems contribute to the autonomy of cars, water networks, precision farms, and more, the more we need to be able to understand how to engineer them and provide guarantees regarding their operation. However, as we do not fully understand how digital systems interact with the physical world, we do not yet have such guarantees. We thus need a science of cyber-physical interaction; related design principles will then emerge, much as they have in other engineering disciplines. Given the importance of the communications substructure for such systems, the jury is still out as to which protocol (or set) will win.

There are many players in the LPWA game, but the big question is what will be the effect of the promised 5G suite of solutions? Finally, as these systems take more control of our lives, their ethical approach is key, including the ability to maintain privacy while still being useful. Indeed, their security is of paramount importance, as being able to hack a water network or autonomous vehicle could mean disaster. There is plenty of research for Europe and beyond to consider.

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DOI:10.1145/3312565

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Women Are Needed in STEM: European Policies and Incentives

WOMEN'S PERSISTENT UNDERREPRESENTATION in science, technology, engineering, and mathematics (STEM) education, occupations, and careers in various parts of the world and its negative impact on STEM labor force and research and innovation (R&I) have given rise to measures, projects, and initiatives aimed at promoting gender equality (GE). In Europe, gender balance in R&I is understood as a social justice and equality issue. Various measures (for example, regulation and research framework, bodies, agencies, funding schemes, prizes, and awards) have been implemented at the European Commission (EC) and European Union (EU) levels to increase women's participation and include the gender dimension in R&I

Achieving GE will significantly advance the STEM labor force, research and innovation, enhance the economy, and reduce the risk of women's social exclusion to the benefit of society.

This article considers the main issues regarding GE in STEM in Europe including an analysis of the reasons for its necessity; a description of the European Union's strategy, measures, initiatives, and activities toward achieving GE; and, finally, their anticipated impact.

Gender Balance in STEM and the Necessity for Gender Equality

The recent momentous growth of the digital production sector offers extended employment opportunities for STEM and ICT-skilled employees. Within the European Union (EU), employment of STEM-skilled personnel increased by 12% between 2000 and 2013.[4,7] According to the *Tech Nation* journal, in the U.K. alone, 1.46 million people (7.5% of the country's workforce) are employed in this sector.[13] Future increases are anticipated. The European Commission (EC) for example, estimates that by 2020 over 900,000 additional employees will be needed in the IT sector whereas for the entire STEM sector, seven million job openings are forecast by 2025.[4]

Despite the good present employment opportunities and the future occupational prospects, European countries face a conspicuous labor shortage in STEM, which tends to be more pronounced in the digital sector.[4–7] The number of young persons pursuing STEM-related studies is decreasing, contrary to the increasing number of university graduates, while a significant proportion of current STEM employees are approaching retirement age.[7] Consequently, ICT- and STEM-related professions are among the top five occupations facing skill shortage in Europe. Excepting Finland, all EU member states lack such professionals.[4] Thus, labor force availability and recruitment in the field are becoming increasingly more challenging. A con-

IMAGE FROM SHUTTERSTOCK.COM

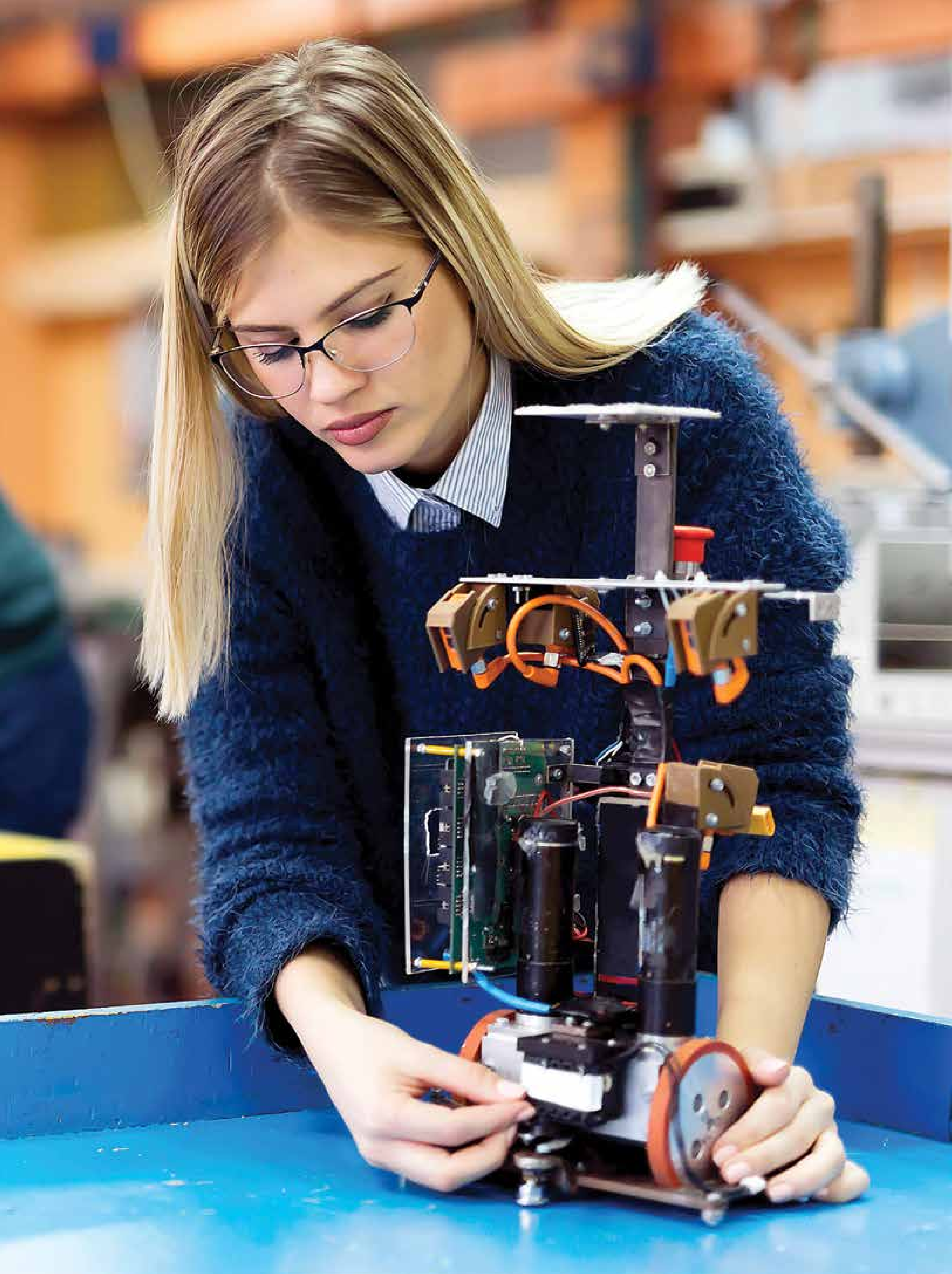


Figure 1. Informatics education in Europe: Institutions, degrees, students, positions, salaries, key data 2012–2017, October 2018. Source: Informatics Europe.

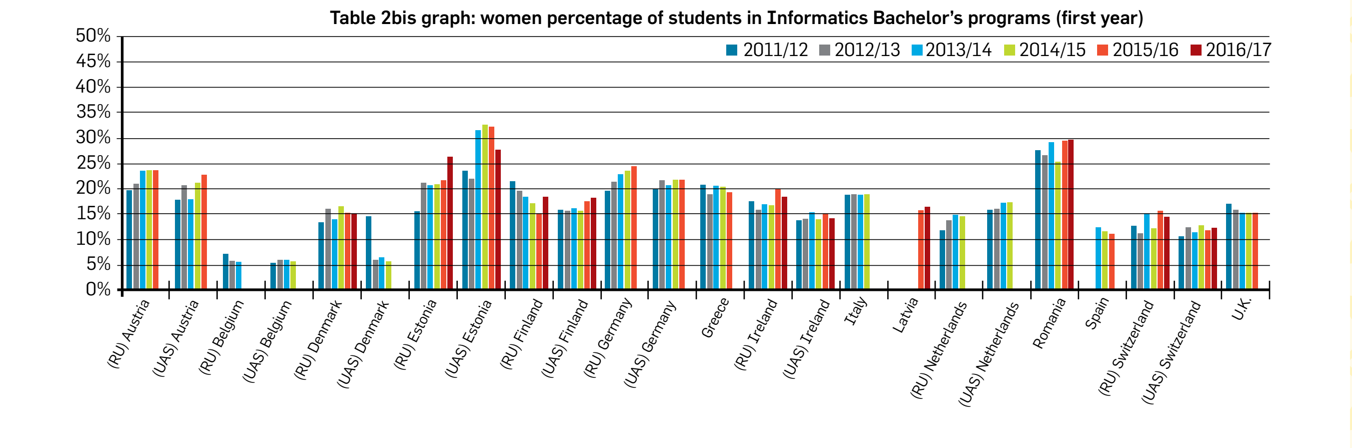
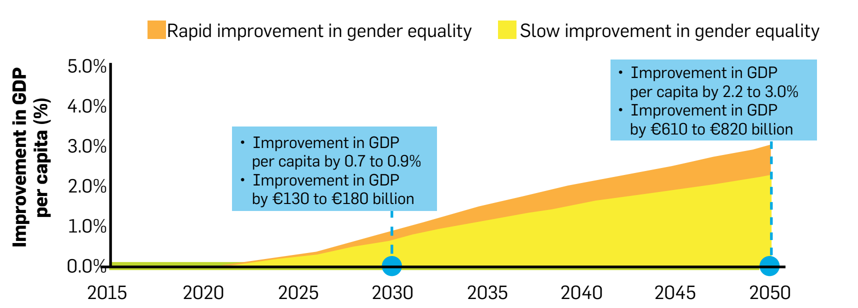


Figure 2. The effect of closing the gender gap in STEM on GDP per capita. Source: European Commission.[6]



Indicative list of non-EC related bodies, agencies, and associations promoting gender equality in ICT in Europe.

Association	URL
ACM-Women Europe	https://europe.acm.org/
Women in Research and Education (WIRE)	http://www.informatics-europe.org/working-groups/women-in-icst-research-and-education.html
Women in High Performance Computing	https://womeninhpc.org/
Athena SWAN	https://www.ecu.ac.uk/equality-charters/athena-swan/
Codess	https://www.codess.net/
Women in Technology and Science	https://witsireland.com/
Women in Games	http://www.womeningames.org/
European Network of Women in Leadership	https://www.wileurope.org/
European Network of Women Web Entrepreneurs Hubs	http://wehubs.eu/
Startup Europe Leaders Club	http://portal.opendiscoveryspace.eu/et/node/822017
European Platform of Women Scientists	https://epws.org/

tributing factor to this challenge is women's persistent underrepresentation.

Indeed, women who choose careers in ICT account for less than 2% of all women in the European labor market while their participation decreases with age (see https://bit.ly/2K4Imdv). Similarly disheartening is women's involvement in innovation and entrepreneurship. For example, women in the EU, parallel to the situation in other parts of the world, constitute less than 25% of science and engineering professionals[3] and only 14% of associate professionals, that is, those who perform research and operational tasks including supervision and control of technical and operational aspects of engineering operations (see https://bit.ly/2GqWBqI for details on these statistics).

According to Catalyst, in 2014 women accounted for less than 1/3 of all employees in scientific research and development across the world (averaged across regions, see https://bit.ly/2zIUJpA). In Australia, for instance, women engineers represent less than 13% of the labor force. In Japan, despite recent measures intended to improve gender ratios in STEM, neither the 20% target of women in science, nor the 15% target of women engineers had been met by 2016. Recent reports estimate that women comprise 39.8% of all researchers in China[12] and refer to the phenomenon of the "missing women in STEM."[14] Similarly, in the U.S., women earning engineering, computer, and information sciences degrees represent less than 20% (data for 2014–2015) of all graduates in these fields and less than 43% in all other STEM fields (see https://bit.ly/2zIUJpA). In India, although gender balance has been achieved with respect to graduation rates in science, IT, and computers (data for 2015–2016), women represent less than 32% of all graduates in the engineering and technology fields. In many European countries women account for less than 20% of all students enrolled in informatics studies (see Figure 1).[9] Concurrently, no significant progress has been observed for the past six years.

This tenacious underrepresentation of women in STEM is further manifested as gender segregation in research and science, gender-related career challenges, gender disproportions in senior positions in academia, gender imbalance in access to research funding, gender-blind and gender-biased research, and organizational culture and institutional process. As detailed in the 2012 report[a] of the EC Expert Group on Structural Change, gender inequalities in research institutions are shaped by: opaqueness in decision making; institutional practices based on unconscious biases in assessment of merit, leadership suitability, and performance evaluation; unconscious gender biases in assessment of excellence and the process of peer review; gender biases in the content of science itself; and a gendered labor organization with implications for research institutions as well. It is, however, progressively acknowledged that including women in STEM studies and professions will enlarge the relative pool of skills, talents, and resources; will enhance the research process and research outcomes; will increase innovation potential; and will boost major sectors of the economy. After all, gender equality refers to equal rights, responsibilities, and opportunities for women and men and girls and boys, and entails consideration of "the interests, needs, and priorities of both women and men."[b]

Within the EU, gender equality in all aspects of social, political, and cultural life, including education and R&I, is approached as a matter of social justice and fairness. GE is included in the EC's priorities and is defined as "promoting equal economic independence for women and men, closing the gender gap, advancing gender balance in decision-making, ending gender-based violence, and promoting gender equality beyond the EU."[c] The official policy for achieving gender equality endorsed by the EU is gender mainstreaming,[d] an internationally embraced strategy that "involves the integration of a gender perspective into the preparation, design, implementation, monitoring, and evaluation of policies, regulatory measures, and spending programs, with a view to promoting equality between women and men and combating discrimination."[e] Toward this end, targeted measures have been developed and actions undertaken at the national and European levels. Although their results vary, and their full potential has not yet been realized, such measures attest to Europe's commitment to gender equality. Here, we present these efforts as they pertain specifically to STEM research and education.

Achieving gender equality will significantly advance the STEM labor force, research and innovation, enhance the economy, and reduce the risk of women's social exclusion to the benefit of society.

The European Union's Strategy and Initiatives for Gender Equality in STEM

The European Commission objectives. Over the years, the EC has developed a regulatory framework on gender equality targeting the labor market and research with three main objectives: gender equality in careers, gender balance in decision-making bodies, and integration of the gender dimension in R&I. Concomitantly, gender equality and mainstreaming are among the Priorities of the European Research Area (ERA),[f] while Article 16 of the Framework Regulation mandates the effective promotion of gender equality and the inclusion of the gender dimension in the R&I content. Thus, gender equality in Horizon 2020[g] (H2020) is both a quantitative

a http://ec.europa.eu/research/science-society/document_library/pdf_06/structural-changes-final-report_en.pdf
b https://eige.europa.eu/rdc/thesaurus/terms/1168
c https://ec.europa.eu/info/policies/justice-and-fundamental-rights/gender-equality_en
d https://bit.ly/2Bg77On
e https://eige.europa.eu/rdc/thesaurus/terms/1185
f http://ec.europa.eu/research/era/index_en.htm
g https://ec.europa.eu/programmes/horizon2020/en/

Within the EU, gender equality in all aspects of social, political, and cultural life, including education and R&I, is approached as a matter of social justice and fairness.

(for example, gender balance in research teams, evaluation panels, advisory boards, expert groups, and so forth) and a qualitative mandate, that is, inclusion of the gender dimension in research.

The EC Advisory Group on Gender in its December 2016 position paper differentiates inclusion of the gender dimension in research from gender balance, which is constituted as "... a dynamic concept that entails researchers taking into account sex and gender in the whole research process, when developing concepts and theories, formulating research questions, collecting and analyzing data using the analytical tools that are specific to each scientific area."[h] The same document provides concrete advice on implementing the gender dimension in research for each H2020 Work Programme including Leadership in Enabling and Industrial Technologies. Conceptually, the EC research framework moves beyond the numerical, sometimes token, inclusion of women in research and ensures that gender and the way it impacts research and its outcomes are meaningfully taken into consideration. On the implementation level, in the EU, Gender Equality bodies, agencies, and associations, both EC and non-EC related, have been founded, and initiatives such as prizes and awards and specifically dedicated funding schemes have been established.

Indicative gender equality-related bodies, agencies, and associations in Europe. The European Institute for Gender Equality (EIGE) is an autonomous body of the EU with the goal to strengthen and promote GE, including gender mainstreaming in all EU and the resulting national policies. EIGE has developed the Gender Equality in Academia and Research (GEAR) Tool that provides a step-by-step guide to preparing GE plans for academic and research organizations. The Helsinki Group on Gender Equality in Research and Innovation, a Standing Working Group of the ERA Committee, brings together representatives from Member States and Associated Countries to advise the European Commission on policies and initiatives on GE in R&I. Since 2005, She Figures and its Statistical Correspondents have published tri-annually pan-European comparable statistics on the current state of GE in R&I, thus serving the crucial goal of monitoring the progress toward GE and the impact of related policies and initiatives.

Focusing specifically on STEM and ICT, the European Centre for Women and Technology (ECWT) is a multiple stakeholder partnership consisting of more than 130 organizations and a significant number of individuals from governments, business, academia, and non-profit sectors with high-level expertise in women in technology development. It aims at increasing the number of girls and women in STEM and integrating a critical mass of women in the design, research, innovation, production, and use of ICT in Europe. Additionally, the European Network for Women in Digital aims at enhancing women's participation in digital studies and occupations across the EU.

An indicative list of non-EC related bodies, agencies, and associations promoting GE issues in the ICT field in Europe is presented in a report by Informatics Europe.[9] Among them, the Athena-SWAN Charter promotes practices to eliminate gender bias and foster an inclusive culture that values female staff, partially through the establishment of prizes and awards. It has been identified as a most effective approach since approximately 82% of U.K. research institutions have adapted their strategies to its Charter scheme.[10]

Prizes and awards. The EU Prize for Women Innovators (https://bit.ly/2tfcrxq) is awarded every year to European women who founded a successful company and brought an innovation to market. The EC Call for Tech StartUps recognizes women who co-own a tech startup. Departments or faculties of EU universities or research institutes and labs that demonstrate a positive impact on women may be candidates for the MINERVA Informatics Europe Equality Award. European women in STEM may also apply for awards of international scope that recognize STEM-related achievements or for (European or international) STEM-related awards that target both genders.

h https://bit.ly/2Tu8dgA

EC funding opportunities and funded projects. GE issues and the gender dimension in research constitute a crosscutting priority in the entire H2020 Work Programme. Nevertheless, a dedicated funding scheme is included in the H2020 Science with and for Society (Swafs) program.[i] Swafs projects contribute to the promotion of Gender Equality Plans (GEPs): A set of actions aimed at conducting impact assessment/audits of procedures and practices to identify gender bias, identifying and implementing innovative strategies to correct bias, and setting targets and monitoring process via indicators.[j] Implementation of the respective GEAR Tool has resulted in examples of best practices on how to attract women into academic leadership positions ensuring, for instance, a gender-balanced representation in the highest decision-making bodies of universities.[k] Nonetheless, Swafs represents only 1.5% of the total budget for all activities under the Societal Challenges section.[8]

With respect to GE in STEM, a significant proportion of EC-funded projects are aimed at structural changes in science, technology, and innovation research organizations and at the inclusion of the gender dimension in research and education. Such projects include (indicatively) GENERA (https://genera-project.com index.php); GEECO (http://www.geecco-project.eu/home), which will set up GEPs for universities and funding organizations in the STEM area; and EFFORTI (https://www.efforti.eu/), aiming at analyzing the influence of measures to promote GE on R&I outputs and on establishing more responsible and responsive research, technology, development, and innovation systems.

A flagship project of particular interest to STEM is Gendered Innovations (http://genderedinnovations.stanford.edu), which specifically addresses the gender dimension of R&I. The project has developed practical methods of gender analysis tailored to the needs of scientists and engineers. More importantly, the project provides peer-reviewed analyses of case studies that evidence the need for considering gender in all stages of research design and implementation in order to produce better science and innovation outputs.

Expected Impact

Measures and initiatives to promote GE in STEM fields have shown positive effects. In Germany, for instance, education initiatives contributed to an increase in the number of women graduating in STEM-related fields.[1] Similarly, women's share among appointed STEM professors has increased by 4.1%.[2,11] Dedicated funding further contributes to an increasing interest in GEP implementation among EU research institutions and organizations (113 organizations through 17 projects up to 2017).

Closing the gender gap in STEM is further expected to increase the scientific quality and societal relevance of produced knowledge, technologies, and innovations; contribute to the production of goods and services better suited to potential markets;[l] and further aid EU economic growth. For example, it is estimated that by 2030 the increase of women's participation in STEM-related fields will increase the EU GDP per capita by 0.7–0.9.[6] In monetary terms, this will lead to 610–820 billion euros improvement in GDP. Furthermore, if effectively implemented, relevant EC measures are expected to increase women's employment, productivity, and wages[4] and thus contribute to long-term competitiveness of the EU economy and improved balance of trade.[6]

Conclusion

Narrowing the gender gap in STEM fields has the potential to increase European labor supply and market activity, make women (and men) better equipped to secure steady and well-paid jobs, and in turn reduce the risk of women's social exclusion, improving both science and society as a whole. C

i A complete list of the projects funded by the FP7 and H2020 programs is provided at https://ec.europa.eu/research/swafs/index.cfm?pg=policy&lib=gender]

j https://eige.europa.eu/gender-mainstreaming/toolkits/gear/what-gender-equality-plan-gep

k Selected abstracts of best practices can be found https://bit.ly/2Gq9q4E.

l https://eige.europa.eu/gender-mainstreaming/policy-areas/research

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DOI:10.1145/3310330

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Informatics as a Fundamental Discipline for the 21st Century

INFORMATICS FOR ALL is a coalition whose aim is to establish informatics as a fundamental discipline to be taken by all students in school. Informatics should be seen as important as mathematics, the sciences, and the various languages. It should be recognized by all as a truly foundational discipline that plays a significant role in education for the 21st century.

The European scene. In Europe, education is a matter left to the individual states. However, education, competencies, and preparedness of the workforce are all important matters for the European Union (EU).

Importantly, there is a recognition that the education systems of Europe do not collectively prepare students sufficiently well for the challenges of the digital economy. These systems need to be fundamentally transformed and modernized. In January 2018, a Digital Education Action Plan,[1] which set out a number of priorities, was published by the EU. The most relevant priority for our initiative is "Developing relevant digital competences and skills for the digital transformation," and the Plan suggests one way to implement this is to "Bring coding classes to all schools in Europe." This is important, but more is needed, as we will explain in this article.

ACM Europe and Informatics Europe. ACM Europe (europe.acm.org) was established in 2008, and Informatics Europe (www.informatics-europe.org) in 2006. From the early days, the two organizations have collaborated on educational matters; through this liaison, they are seen to project to the wider community a single message about aspects of informatics[a] education. In 2013, the two groups set up and funded a Committee on European Computing Education (CECE) to undertake a study that would capture the state of informatics education across the administrative units of Europe (generally, these units are the countries, but within Germany, for instance, there are 14 different administrative units with autonomy regarding education).

The CECE study paralleled the highly influential U.S. study *Running on Empty*[11] that had drawn attention to the state of computer science education in the U.S. The CECE study gathered data from 55 administrative units (countries, nations, and regions) of Europe (plus Israel) with autonomous educational systems through the use of questionnaires and a wide network of reliable contacts and official sources.

The report on that work was published in 2017.[3] The three themes of informatics, digital literacy, and teacher training provided the framework for the study. Informatics was

a In most of Europe, informatics is synonymous with computing or computer science.


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defined as knowledge and competencies about computational structures, processes, artifacts, and systems. Digital literacy was seen as basic user skills, such as conversancy with standard tools like word processors, Web browsers, spreadsheets, and so on.

While the report confirmed that, across Europe, there was a growing realization of the importance of sound school education in informatics, it also showed a largely variable level of effort and achievement across administrative units. For instance, the report found that informatics was available to all pupils in only 22 out of 50 units, while in a further 10 units it was available to just some students, and in several noticeable cases, no informatics teaching was available at all. When students could elect to take an informatics course, there was evidence of poor uptake, often as low as 10%.

The authors of the CECE report included a number of recommendations that would serve to improve the situation. Those recommendations addressed each of the three areas (informatics, digital literacy, and teacher training), and these form the basis of the Informatics for All initiative.

Informatics for All

The task of moving forward with the CECE recommendations was seen as different in character from the survey work. Importantly, the Informatics for All Coalition was formed by the joint efforts of ACM Europe, Informatics Europe, and the Council of European Professional Informatics Societies.[4] These organizations all share a common concern about the state of informatics education throughout Europe, and are committed to stimulating activity that will lead to significant improvement.

In moving forward, the new organization took the opportunity to present a perspective on informatics education that would reflect the advances that have occurred since 2014, when the CECE work properly began.

Building on the CECE recommendations, the report *Informatics for All: The Strategy*[12] was produced. The emphasis of the report is on informatics education, with informatics seen as the science underpinning the development of the digital world—a distinctive discipline with its own scientific methods, its own ways of thinking, and its own technological developments.

By emphasizing the constructive and creative elements of the discipline, the role of informatics in innovation and discovery and its role in shaping the digital world, the discipline is seen as an essential element of education for the 21st century. Its role in competitiveness and in the economic prosperity of Europe (and beyond) further adds to its vital nature.

The report, which contains eight recommendations (see the accompanying figure), was formally launched in Brussels in March 2018. The launch was attended by representatives of the European Commission as well as representatives of industry and academia; it received uniform, enthusiastic support.

Two-tier strategy. In many ways, the Informatics for All initiative mirrors the CS for All initiative launched in the U.S. in early 2016 (see sidebar). A crucial element of the European approach, which distinguishes it from the CS for All initiative, is the two-tier strategy at all educational levels: Informatics as an area of specialization, that is, a fundamental and independent subject in school; and the integration of informatics with other school subjects, as well as with study programs in higher education. Perhaps overly simplified, the two tiers

The eight recommendations from *Informatics for All: The Strategy*.[12]

Curriculum Considerations

- All students must have access to ongoing education in informatics in the school system. Informatics teaching should start in primary school.
- Informatics curricula should reflect the scientific and constructive nature of the discipline, and be seen as fundamental to 21st century education by all stakeholders (including educators, pupils, and their parents).
- Informatics courses must be compulsory and recognized by each country's educational system as being at least on a par with courses in STEM (Science, Technology, Engineering, and Mathematics) disciplines. In particular, they must attract equivalent credit, for example, for the purposes of university entrance.

Preparing Teachers

- All teachers at all levels should be digitally literate. In particular, trainee teachers should be proficient (via properly assessed courses) in digital literacy and those aspects of informatics that support learning.
- Informatics teachers should have appropriate formal informatics education, teacher training, and certification.
- Higher education institutions, departments of education, as well as departments of informatics should provide pre-service and in-service programs, encouraging students to enter a teaching career related to informatics.
- Ministries should be encouraged to establish national or regional centers facilitating the development of communities of informatics teachers who share their experiences, keep abreast of scientific advances, and undertake ongoing professional development.

Teaching the Teachers

- Intensive research on three different facets, curriculum, teaching methods and tools, and teaching the teachers is needed to successfully introduce informatics into the school system.

The U.S. Initiative CS for All

The CS for All initiative, launched by President Barack Obama on January 30, 2016,[6] was highly imaginative and a catalyst for a burst of initiatives in computer science (CS) education in the U.S. It fired the imagination and provided a focus for great activity centered on the promotion of CS at all stages of education. The financial commitments were impressive, even eye-watering!

The initiative could be seen as the culmination of earlier work on CS education supported by the National Science Foundation (NSF), the CS Principles course launched by the College Board,[7] the extensive work of the Computer Science Teachers Association (CSTA),[8] and efforts by ACM, by code.org, and by many others. Within ACM, the efforts included work on policy matters by the Education Policy Committee, harnessing the invaluable support of major industrial players through Computing in the Core (which has now merged with the code.org Advocacy Coalition), lobbying on Capitol Hill, as well as actions from groups with members in the ACM Education Council.

may be characterized as Learn to Compute (specialization) and Compute to Learn (integration).

All students—regardless of their special interest, area of expertise, and future profession—need to be educated in informatics and apply those knowledge and skills as an integrated competence in all subjects and professions. In so doing, they must ensure that technological development is directed towards the achievement of a better, safer, fairer, and more just society.

The second tier of the strategy, integrating informatics with other disciplines, has huge educational potential.

Through digital models, subjects can be taught in novel and more engaging ways, and data-driven approaches will open doors to new dimensions of understanding and new ways of learning subjects. Similarly, through programming of, say, simulations and games, knowledge and insight in a subject can be expressed in more individual, novel, useful, and creative ways (instead of the traditional reproduction of knowledge in written or oral form).

By integrating informatics in other disciplines, students are provided the advantage of having an additional novel, specific way of thinking to describe and explain phenomena (often referred to as "computational thinking"), complementing that of other scientific disciplines and contributing to their better, more thorough understanding. This is pursued even in STEM, for example, Weintrop,[16] and K–12 SF.[14]

Implementation

The challenge now for the Informatics for All Committee is to bring about change leading to the realization of the strategy. It is highly unlikely that the recommendations will simply be mandated; rather, a carefully considered approach that leads toward the acceptance of the recommendations seems far more realistic.

The implementation problem has to be addressed within each country where responsibility for education resides. Within each country, groups consisting of administrators, academics, teachers, industrialists, employers, and others, could come together and (with sensitivity and caution) create pressure and initiatives that would lead to change as required.

There are different areas of responsibility and different possible activities within these areas:

Education authorities. Administrators have responsibility for the proper recognition of disciplines, and related matters. Accordingly, they have a role in the implementation of certain aspects of the recommendations:

- recognition of informatics as a science,
- the education of teachers of informatics, and
- the education of all teachers.

Curriculum development (includes pupils and parents). Within the CECE report, there are comments that suggest current informatics curricula are not uniformly popular with pupils and their parents. For informatics to be a discipline taken by all, there is a need to review and revise (and in some cases, design) curricula to ensure the discipline is considered an essential one for the 21st century by all stakeholders, including students and their parents.

The motivation of students must be heightened dramatically; all students, including the best students, must see informatics as highly relevant. The curriculum is predominantly technical in nature, and has to capture the essence of the discipline, emphasizing the relevance to people and society in general and to the young in particular, thus including fundamental issues with the practical and more theoretical aspects being carefully interwoven. To motivate students, attention can be drawn to creativity, innovation, and applications, and the massive impact these have on society, particularly highlighting the use of big/deep data, Internet of Things, and developments in machine learning and their impact on the 'future of work.'

Role of higher education. Within higher education institutions (HEI), expertise should be mobilized to support the development of competence and capacity. There are four main aspects:

The emphasis of the report is on informatics education, with informatics seen as the science underpinning the development of the digital world—a distinctive discipline with its own scientific methods, its own ways of thinking, and its own technological development.

The challenge now for the Informatics for All Committee is to bring about change leading to the realization of the strategy.

▸ Staff in HEIs can provide expertise and advice to guide developments, such as in advising on relevant curricular standards (detailing what can and should be taught at different stages of school education).

▸ HEIs often are engaged in the education and training of teachers, and in their professional development. Their forward thinking can serve to continually improve teaching expertise; this can happen at the stage of initial teacher education, and through continuing professional development.

▸ Within HEIs, research typically features strongly, and the Informatics for All strategy stresses the importance of research. In this context, HEIs might partner with schoolteachers, educationists, and/or others to drive forward relevant research agendas.

▸ HEIs are a powerful force, perhaps the single most powerful force, in terms of influencing the delivery of the curriculum in schools. What are the requirements for entry to specific programs of study?

Role of professional bodies and the EU. Professional bodies, such as the Council of European Professional Informatics Societies (CEPIS), will typically have strong links with industry and will be in a position to effectively harness industrial perspectives; they typically will be recognized as such by government. It is expected that they will voice strong views about the need for informatics education, especially in relation to the economic development of the country and workforce planning. Where their feelings are particularly strong, they can bring pressure to bear at the governmental level to provide national resources for teacher training, research, and more. They also may be able to provide resources to aid education. It would also be desirable to complement the EU's Digital Action Plan with national initiatives, possibly supported by EC resources.

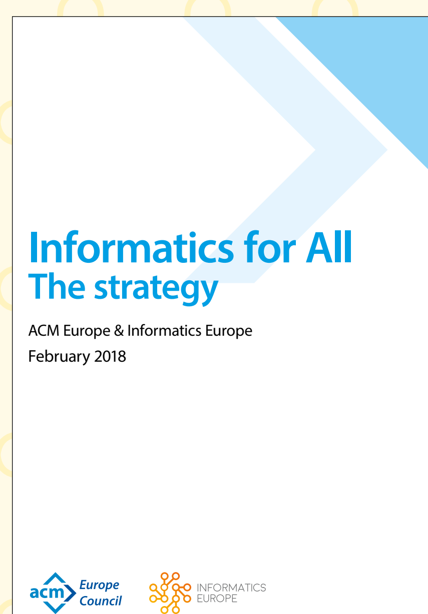
Curriculum issues. Adopting a completely new subject to a national school curriculum is challenging for many reasons. A general but very concrete challenge is how to provide the necessary space in the curricula. We do not believe that the school system of 2019 has reached a fixed point with respect to mandatory subjects; thus, in whichever way possible, space must be found. We feel that each country will have to find her own solution, matching her constraints and situation.

As mentioned, a curriculum should include the foundations of the discipline, including theoretical and implementation aspects. Clearly it should not be just a downgrade of university curricula, but a curriculum should be specially designed for each school level (elementary, middle, and high school). New curricula research should be conducted to examine and find the appropriate methodology and pedagogy to design such curricula for the different levels of school.

Human and Societal Perspectives

Informatics dramatically differs from other sciences in terms of the way it empowers. With informatics, there is powerful support for automating cognitive tasks[15] and this has implications for all domains and professions. Moreover, the related concept of computational thinking is recognized as having relevance more widely.[2,17,18]

In Iversen,[13] the concept of computational empowerment is seen as an important development of computational thinking that places an emphasis on the abilities needed to effectively deploy informatics. Based on a critical analysis of current tech-



nologies, it pulls together technological insights and innovation and links these to the role that informatics plays in the development of personal life and of society. In this way, future generations will have the knowledge and skills from informatics to become competent, constructive, and critical co-creators of the digital future.

In a context where informatics education begins early in primary school and is carried forward through to the later years of high school, there is the opportunity to develop thoughts about the possible wider relevance of ideas from informatics, and to develop them in a meaningful way that places emphasis on the human (and societal) benefits and implications. Just making suggestions about possible improvements opens the door to considerations about (software-inspired) innovation, and more.

It is important that students acknowledge software as creator and bearer of values and culture—that these aspects are explicitly or implicitly embedded in the software. Software is formed through design processes that include critical decision-making; students must learn to creatively develop software, and learn to analyze and understand the impacts of software and digital artifacts in general. For example, these visions for a strong human and societal perspective are thoroughly embedded in the newly designed Danish curriculum for informatics in school.[9]

Augmented intelligence. The concept of augmented intelligence relates to the effective use of informatics in augmenting human intelligence. The discussion above regarding STEM was one instance of that though even there, there is scope for extending that further.

Developments in language translation, voice recognition and simulation, and related advances fueled by developments in machine learning suggest great scope for reshaping the curriculum in many disciplines.

The role of ethics. Those who develop software ought to do so in a responsible manner, ensuring that 'bad things' do not happen. The related issues tend to be captured in a code of conduct that provides guidance on good practice. In the past, such codes have tended to stress matters such as 'do not cause harm'. While this remains important, a more enlightened approach places an emphasis on contributing positively to the benefit of a fair, just, and secure society through the use of computers and computing. The recent ACM Code of Ethics and Professional Conduct[5] takes such a view.

The role of teachers. Teachers are the key to the success of the implementation of any study program and the introduction of any new curriculum or technologies. A good supply of well-educated and enthusiastic teachers is crucial to support every discipline in schools at all levels, but the lack of suitable teachers at all levels also forms a bottleneck for the successful implementation of Informatics for All. Thus, efforts should be devoted to recruitment, and to establishing a supportive informatics teacher community.

Concluding Remarks

The primary focus of Informatics for All is to stimulate the recognition that informatics is a vital, important discipline, both as a subject of study on its own, and also integrated with other disciplines with many of the ideas having relevance more broadly.

The two-tier approach facilitates the integration of informatics into the teaching of other disciplines, reshaping the curriculum for all disciplines and generally providing a basis for making education systems truly relevant for the 21st century. It also opens up many avenues for research; for instance, about how to teach disciplines effectively in a world of constant change.

Given that digital technology is taking an increasingly relevant and pervasive role, providing to all citizens an appropriate level of informatics education is necessary to ensure balanced development of the digital society.

Informatics for All is a catalyst for important thoughts for reforming the wider educational systems to the benefit of students and employers, and ultimately the economy of Europe.

Acknowledgments. The authors wish to acknowledge contributions and support from various quarters: Wendy Hall, Bob McLaughlin, Bobby Schnabel and the board members of ACM Europe, Informatics Europe, and the original CECE team.

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DOI:10.1145/3311783

BY PAOLA INVERARDI

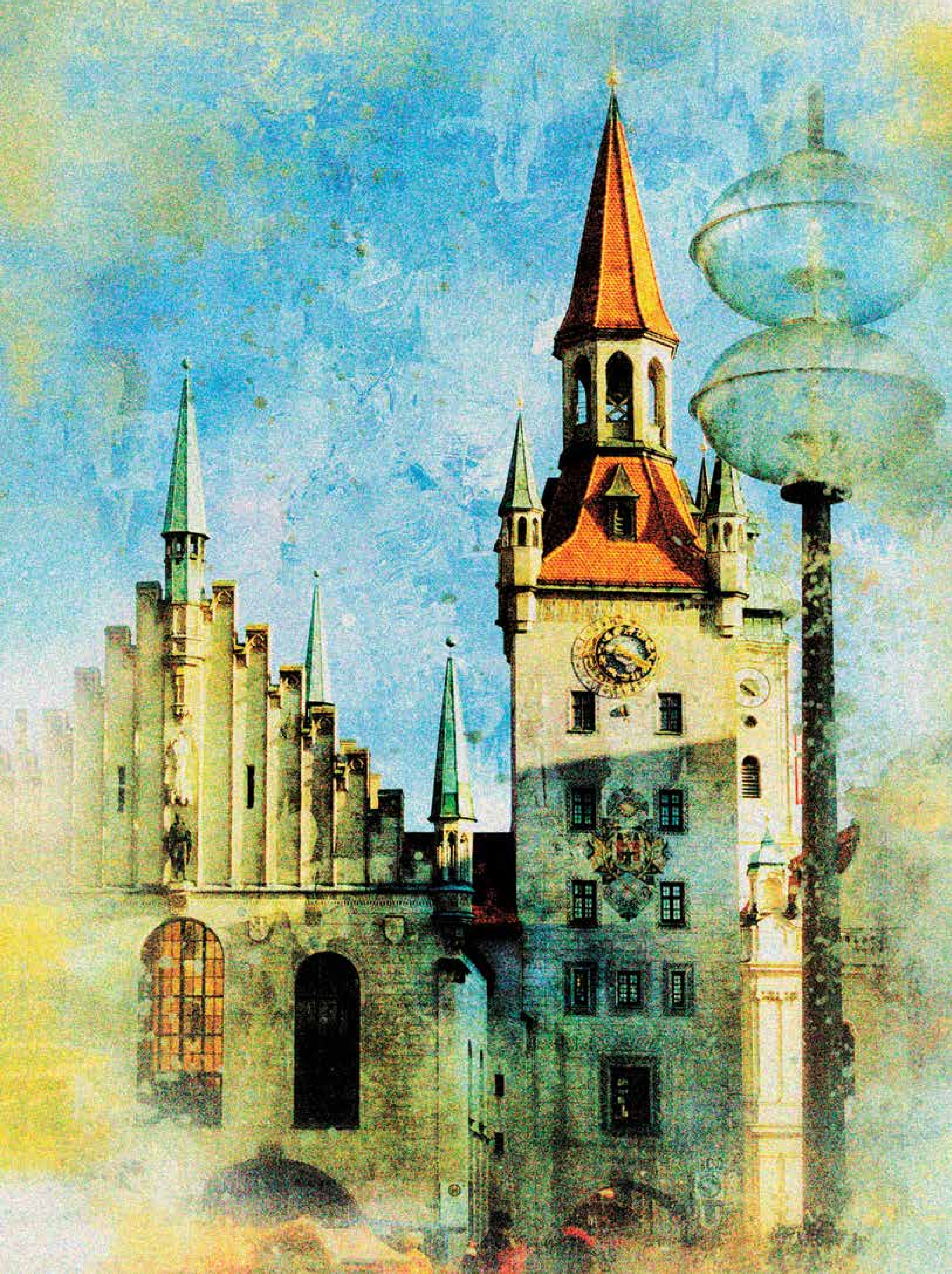
The European Perspective on Responsible Computing

WE LIVE IN the digital world, where every day we interact with digital systems either through a mobile device or from inside a car. These systems are increasingly autonomous in making decisions over and above their users or on behalf of them. As a consequence, ethical issues—privacy ones included (for example, unauthorized disclosure and mining of personal data, access to restricted resources)—are emerging as matters of utmost concern since they affect the moral rights of each human being and have an impact on the social, economic, and political spheres.

Europe is at the forefront of the regulation and reflections on these issues through its institutional bodies. Privacy with respect to the processing of personal data is recognized as part of the fundamental rights and freedoms of individuals. Regulation (EC) 45/2001 establishes the rules for data protection in the EU institutions and the creation of the *European Data Protection Supervisor* (EDPS) as independent supervisory authority to monitor and ensure people's right to privacy when EU institutions and bodies process their personal data. The *European Group on Ethics in Science and New Technologies* (EGE) is an independent advisory body of the President of the European Commission that advises on all aspects of Commission policies and legislation where ethical, societal, and fundamental rights dimensions intersect with the development of science and new technologies. In 2015, the EDPS appointed the Ethics Advisory Group (EAG) "to explore the relationships between human rights, technology, markets, and business models in the 21st century."

Autonomous systems. We broadly define autonomous systems as systems that have the ability of substituting humans in supplying (contextual) information that the system may use to make decisions while continuously running. Depending on the nature, property, and use of this information, an autonomous system may impact moral rights of the users, be they single citizens, groups, or the society as a whole. The widespread use of AI techniques in the implementation of these systems has exacerbated the problem contributing to the creation of systems and technologies whose behavior is intrinsically opaque.[1,2,14] In this article, we will stick to the notion of autonomous technology rather than with AI technology. Indeed, we are concerned with the autonomous decision-making capabilities of systems even if those capabilities are a consequence of the availability of more and more complex AI enabling technologies.

The harm of digital society. The last years have witnessed an increasing rate of concerns on the impact of autonomous technologies on our societies. Economy, politics, and human being natural rights are endan-



The GDPR aims to give individuals control over their personal data and to provide a unifying regulation within the EU for international business.

gered by the uncontrolled use of autonomous technology. Institutional as well as social and scientific entities and boards contribute to constantly feeding the debate by advocating and proposing codes of ethics for developers and regulations from governmental bodies.[1-3,12-15,21,22] Admittedly, this debate is mostly concentrated in western countries although with different regulatory outcomes. Indeed, ethical principles, notably privacy, may vary from country to country due to their specific culture and history[16,27] and to the impact the development of autonomic technologies can have on the economy of the country. However, at least in western countries there is growing consensus that it is time to take actions to address the harms of autonomous technologies[15] and that those actions need eventually to have a regulatory nature and be part of public policy.[18,19] To this respect, Europe is certainly far ahead both in thinking and regulation.

The General Data Protection Regulation (GDPR), which is the most advanced in the world regulation on personal data protection, is Europe's most relevant achievement so far. By comparison, the state of California recently passed a digital privacy law that will go into effect in January 2020. Although more limited in scope than GDPR, the law is considered one of the most comprehensive in the U.S.[20] In a recent paper, "Constitutional Democracy and Technology in the Age of Artificial Intelligence,"[19] Paul Nemitz, Principal Advisor of the European Commission, claimed that "The EU GDPR is the first piece of legislation for AI." He provides a comprehensive account of the debate and of the process that accompanied the formulation and adoption of GDPR. Nemitz points out that as happened with GDPR concerning personal data protection, AI and autonomous technologies need to be regulated by laws as far as individual fundamental rights and democracy of society are concerned.

This would lead to accept AI-based autonomous technologies only "if by design, the principles of democracy, rule of law, and compliance with fundamental rights are incorporated in AI, thus from the outset of program development," Nemitz writes.

The quest for an ethical approach. For years, Europe has called for a more comprehensive approach that encompasses privacy and addresses ethical issues in the scope of the digital society. The EDPS in its strategy for 2015–2019 sets out the goal to develop an ethical dimension to data protection.[4] In order to reach the goal, it has established the EAG with the mandate to steer a reflection on the ethical implications that the digital world emerging from the present technological trends puts forward. EDPS 4/2015 Opinion "Toward a new digital ethics,"[3] identifies the fundamental right to privacy and the protection of personal data as core elements of the new digital ethics necessary to preserve human dignity as stated in Article 1 of the EU Charter of Fundamental Rights. The Opinion also calls for a big data protection ecosystem that shall involve developers, businesses, regulators, and individuals in order to provide 'future-oriented regulation,' 'accountable controllers,' 'privacy-conscious engineering,' and 'empowered individuals.'

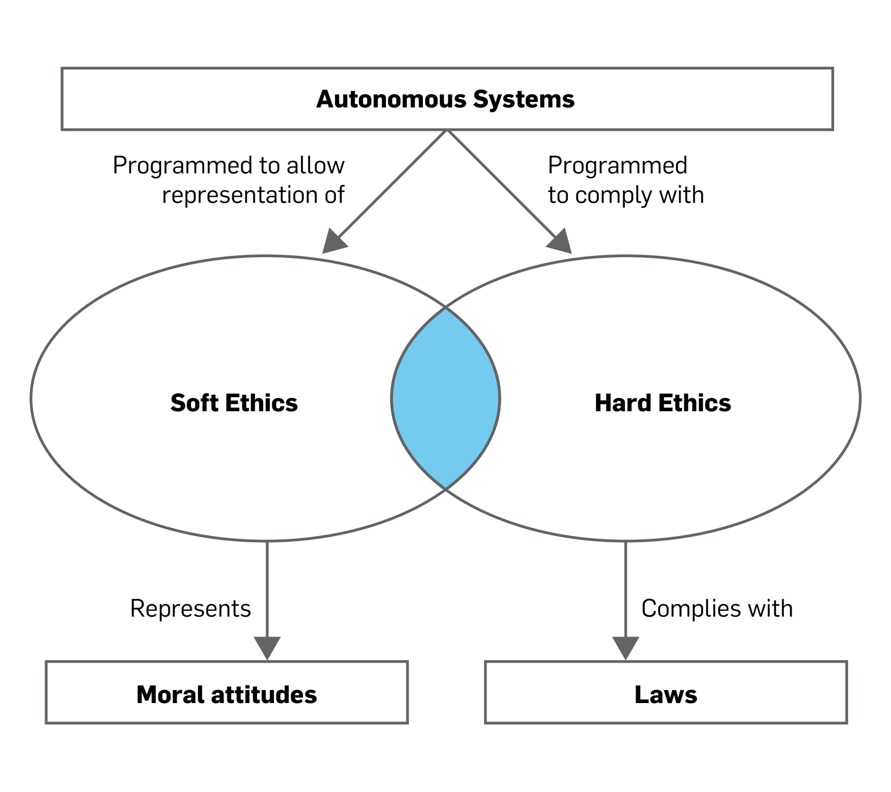
In its 2018 report,[6] the EAG has provided a broader set of reflections on the notion of digital ethics that address the "fundamental questions about what it means to make claims about ethics and human conduct in the digital age, when the baseline conditions of humanness are under the pressure of interconnectivity, algorithmic decision-making, machine-learning, digital surveillance, and the enormous collection of personal data." In March 2018, the EGE released a statement on "artificial intelligence, robotics, and 'autonomous' systems" in which it urges an overall rethinking of the values around which the digital society is to be structured.[5] Computer scientists, besides other societal actors, are called to join this effort by contributing theories, methods, and tools to build trustable and societal-friendly systems. "Advances in AI, robotics and so-called 'autonomous' technologies have ushered in a range of increasingly urgent and complex moral questions," the EGE states. "Current efforts to find answers to the ethical, societal, and legal challenges that they pose and to orient them for the common good represent a patchwork of disparate initiatives. This underlines the need for a collective, wide-ranging, and inclusive process of reflection and dialogue, a dialogue that focuses on the values around which we want to organize society and on the role that technologies should play in it."

In its statement, the EGE goes further and proposes "a set of basic principles and democratic prerequisites, based on the fundamental values laid down in the EU Treaties and in the EU Charter of Fundamental Rights." The first one restates human dignity in the context of the digital society: "(a) Human dignity, The principle of human dignity, understood as the recognition of the inherent human state of being worthy of respect, must not be violated by 'autonomous' technologies."

Supporting ethical concerns in autonomous systems. Europe is thus calling for a digital society in which the human being with fundamental rights remains at its center. Therefore, there is the need to rethink the role of the various actors in the digital world by empowering the users of the digital technology both when they operate as citizens and as individuals. However, what does it mean to empower the citizens and the individuals?

Human at the center. The stated principle of human dignity indicates that individuals need to be able to exercise some degree of control on their information and on the decisions that autonomous systems make on their behalf. This raises an issue of what is the scope of system autonomy. Indeed, the principle asks for autonomous systems that, in their behavior, pay respect to human's decisions and beliefs. This means that system's autonomy is a direct consequence of the amount and kind of respect of the individuals they interact with. The more individuals the system interacts with the less autonomy may be given to potential conflicts of respect. This is clearly understood in the scope of privacy where different individuals may have different privacy concerns about their personal data both in general and also depending on given contexts. Reflections on digital ethics can help us in shaping the scope of system autonomy.

A conceptualization of the relationship between digital ethics and autonomous systems.



Digital ethics. Luciano Floridi, a professor of philosophy and the ethics of information at Oxford and director of the Digital Ethics Lab of the Oxford Internet Institute, defines digital ethics[7] as the branch of ethics that aims at formulating and supporting morally good solutions through the study of moral problems relating to personal data, AI algorithms, and corresponding practices and infrastructures. Simplifying, he further identifies two separate components of digital ethics, hard and soft ethics. Hard ethics is defined and enforced by legislation. However, legislation is necessary but insufficient, since it does not cover everything, nor should it. In the space that is left open by regulation, the actors of the digital world, for example, companies, citizens, and individuals, should exploit digital ethics in order to forge and characterize their identity and role in the digital world. This is the domain of soft ethics, which deals with what ought and ought not to be done over and above the existing regulation, without trying to bypass or change the hard ethics.

From the user perspective, soft ethics is where individual ethical values can be expressed; hard ethics characterizes the values, defined by the legislation, a digital system producer shall comply with. Soft ethics is therefore the context in which a user's control of autonomous technology shall and can be exercised.

A patchwork of approaches. Besides reflections and statements on ethics, Europe has put in place a number of initiatives that on the one side represent a patchwork according to the EGE, and on the other side they show that ethical concerns are at the core of the interest for the European society at a whole. A few examples follow:

From a regulatory standpoint, the GDPR was entered into application throughout the EU in May 2018. Article 1 states that: "Regulation lays down rules relating to the *protection of natural persons* with regard to the processing of personal data and rules relating to the free movement of personal data. This Regulation protects *fundamental rights* and *freedoms of natural persons* and in particular

Users need to be able to verify the system they use by possibly imposing on them their own ethical requirements.

their *right to the protection of personal data*."

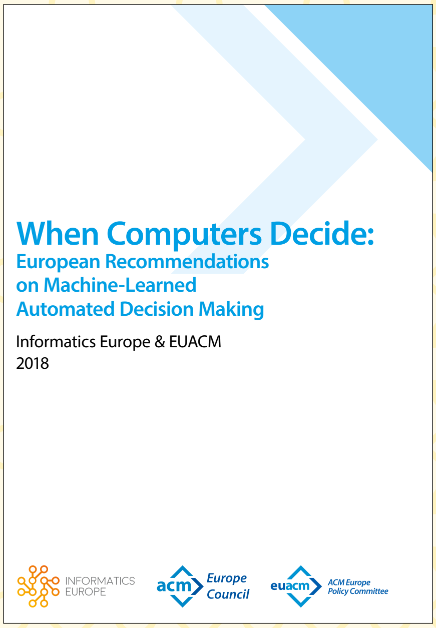
The GDPR aims to give individuals control over their personal data and to provide a unifying regulation within the EU for international business. It states data protection rules for all companies operating in the EU, whether they are established in the EU or just operating inside the EU. This regulation forces controllers of personal data to shape their organization and their processing systems in order to implement the data protection principles. As already mentioned, GDPR is the most advanced regulation about personal data operating in the world.

Through its organizations, the scientific community has contributed (at a policy level) to identify problems and establish criteria to develop algorithms and systems that embed machine-learning-fueled autonomous capabilities. In March 2018, the ACM Europe Council, the ACM Europe Policy Committee (EUACM), and Informatics Europe presented a white paper on "When Computers Decide: European Recommendations on Machine-Learned Automated Decision Making."[2] The report critically analyzes the implications of the increasing adoption of machine learning automated decision making in modern autonomous systems. It concludes with a set of recommendations for policy-makers that concern the technical, ethical, legal, economic, societal, and educational dimensions of the digital society.

DECODE is a consortium of 14 European organizations (municipalities, companies, research institutions, foundations) led by the municipality of Barcelona. DECODE is developing a project, funded by the European Commission through its research programs Horizon 2020,[8] whose aim is to empower citizens to control their personal information over the Internet. It provides a distributed platform and tools that use blockchain technology with attribute-based cryptography to give people control of how their data is accessed and used. DECODE experiments through pilots deployed in Amsterdam and Barcelona. The pilots focus on the Internet of Things, collaborative economy and open democracy. The DECODE project was selected in response to a call that stated the following objective: "The goal is to provide SMEs, social enterprises, industries, researchers, communities and individuals with a new development platform, which is intrinsically protective of the digital sovereignty of European citizens."

Beyond privacy, in particular regarding the potential conflict between user/social ethical principles and autonomous systems decisions, ethical issues insistently emerged in the autonomous cars domain. Indeed, there is no general consensus on which ethical principles (personal ethics settings versus mandatory ethics setting) need to be embedded, and how, in the control software of autonomous vehicles.[9,10] In 2016, the German Federal Ministry of Transport and Digital Infrastructures appointed an ethical committee that produced a recommendation report resulting in 20 ethics rules for automated and connected vehicular traffic.[11] In particular, rules 4 and 6 mention the ethical principle of safeguarding the freedom of individuals to make responsible decisions and the need to balance that with the freedom and safety of others.

Challenges for computer scientists. Responsible computing as defined in the European perspective sets out a number of ambitious challenges for computer scientists.



Empowering the user requires a complete rethinking of the role of the user in the digital society. The user is no longer a passive consumer of digital technologies and a data producer for them. Her dignity as a human being implies ownership of personal data and freedom of making responsible decisions. Autonomous technologies shall be designed and developed to respect it. This lifts the user to become an independent actor in the digital society able to properly interact with the autonomous technologies she uses every day and equipped with the appropriate digital means.

The separation of digital ethics in hard and soft ethics suggests that hard ethics is what the autonomous system shall comply with while soft ethics is specific to each individual/user. To obey the principle of human dignity the system during its interactions with each individual shall not violate her soft ethics. The autonomous system architecture shall permit this interaction to happen by complying with the user's moral prerogatives and capabilities. Users need to be able to verify the system they use by possibly imposing on them their own ethical requirements. The separation of concerns implied by the above notion of digital ethics suggests an overall framework in which the autonomy of the system is delimited by hard ethics requirements, users are empowered with their own soft ethics, and the interactions between the system and each user are further constrained by their soft ethics requirements. Therefore, the capability of an autonomous system to make decisions does not only need to comply with legislation but also with a user's moral preferences. (See the intersection between soft and hard ethics in the accompanying figure.)

In such a framework, it should also be possible to deal with liability issues in a fine-grained way by distributing responsibility between the system and the user(s) according to hard and soft ethics. The envisioned framework requires several steps. On the ethics side, provided that autonomous systems will be developed by complying with hard ethics that is with the regulations, the crucial issue to face is to respect each individual's soft ethics. If verifying the compliance of autonomous systems to hard ethics is already raising huge scientific interest and great worries (given the use of obscure AI techniques),[1,2,14] defining the scope of soft ethics and characterizing individual ones is a daunting task. Indeed, neither a person nor a society applies moral categories separately. Rather, everyday morality is in constant flux among norms, utilitarian assessment of consequences, and evaluation of virtues. Nevertheless, a digital society that fully realizes the principle of human dignity shall allow each individual to express her soft ethics preferences. Further challenges concern means to consistently combine user soft ethics with system hard ethics and to manage interactions of the system with users endorsing different ethics preferences. Autonomous systems shall be realized by embedding hard ethics by design but remaining open to accommodate users' soft ethics. This could be achieved through system customization or by mediating interactions between the system and the user, in any case through rethinking the system architecture.

Building systems that embody ethical principles by design may also permit acquiring a competitive advantage in the market, as predicted in the recent Gartner Top 10 Strategic Technology Trends for 2019.[23]

Computer scientists alone cannot solve the scientific and technical challenges we have ahead. A multidisciplinary effort is needed that calls for philosophers, sociologists, law specialists, and computer scientists working together.

Acknowledgments. The author is indebted to the multi-disciplinary team of the EXOSOUL@univaq project (http://exosoul.disim.univaq.it) for enlightening debates and joint work on digital ethics for autonomous systems.

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big trends

DOI:10.1145/3312567

BY THOMAS SKORDAS

Toward a European Exascale Ecosystem: The EuroHPC Joint Undertaking

HIGH-PERFORMANCE COMPUTING (HPC, also known as supercomputing) is indispensable in the new global data economy. The dramatic increase in the volume and variety of big data is creating new possibilities for sharing knowledge, carrying out scientific research, doing business, and developing public policies.

In almost every scientific discipline, researchers are using complex HPC modeling and simulation techniques and big data analytics approaches to answer fundamental questions and make new discoveries and breakthroughs. Representative examples include: in biology and the life sciences, understanding the dynamics of biomolecules and proteins and genome sequencing and genome assembly; in materials science and pharmaceutics, designing new materials and discovering new drugs; and in cosmology and astrophysics, understanding dark matter. HPC also provides solutions to complex problems (such as understanding the organization and functioning of the human brain, developing new treatments based on personalized medicine, and predicting and managing the effects of climate change).

In industry, HPC paves the way for new businesses and innovative applications in high-added-value areas (such as manufacturing and engineering, particularly automotive and aeronautical engineering, oil and gas exploration, bioengineering and mo-

IMAGE BY SASHKIN

lecular chemistry, agri-food and precision agriculture, and developing and managing renewable and clean energies). In all these areas, HPC helps reinforce industrial innovation capabilities, particularly in small and medium-size enterprises (SMEs).

HPC is also becoming a key tool for public decision making in an increasing number of areas (such as in cybersecurity and defense, including developing efficient encryption technologies, and understanding and responding to cyberattacks and cyberwars, in nuclear simulations, in the fight against terrorism and crime, and in understanding and managing natural hazards and biological risks, including earthquakes, flooding, failure of dams or power plants, and health pandemics).

HPC in Europe

In combination with artificial intelligence, HPC is set to become the engine to power the new global digital economy, where to out-compute is to out-compete. In this context, European supercomputing infrastructures represent a strategic resource for understanding and responding to the increasing challenges European citizens will face in the years to come, as well as for the future of European industry, SMEs, and the creation of new jobs. They are also key to ensuring European scientists reap the full benefit of data-driven science.

However, today the European Union (EU) is not investing enough in HPC infrastructures and technologies to match its economic and knowledge potential, showing an annual funding gap of more than €500 million compared with the U.S. and China.

Europe needs an integrated leading-class HPC and data infrastructure with exascale computing performance that can compete worldwide. This infrastructure is absolutely necessary to ensure data produced in Europe by academia, industry, and SMEs is processed with its own su-

HPC is set to become the engine to power the new global digital economy, where to out-compute is to out-compete.

percomputing and data capabilities. This would reduce Europe's dependence on facilities in third countries and encourage innovation to stay in Europe.

Europe's Strategic Objectives

One of the priorities of the European Commission is to place Europe in the first three supercomputing powers of the world.[a] To achieve this ambition, in October 2018 the EU, together with 24 EU member states and Norway, established the European High Performance Computing Joint Undertaking (EuroHPC JU),[b] a public-private partnership between the EU, the 25 participating countries, and two European HPC and big data industrial associations—ETP4HPC[c] and BDVA.[d]

The EuroHPC JU is a legal and funding entity that makes it possible to combine EU and national funding with private resources. Its mission will be to develop, deploy, extend, and maintain in the EU an integrated world-class supercomputing and data infrastructure and develop and support a highly competitive and innovative HPC ecosystem. EuroHPC will enable the EU and the participating countries to coordinate their supercomputing research agendas and investments and pool national and EU resources to close the funding gap with global competitors. The overall goals of the EuroHPC JU will be:

Acquire world-class supercomputers. To acquire world-class supercomputers available to European users from academia, industry, SMEs, and the public sector, including two pre-exascale systems by 2020, two exascale systems by 2022/2023 (at least one with European technology), and post-exascale supercomputers;

Maintain EU leadership. To maintain the EU's leadership in scientific and industrial applications, including HPC Competence Centres facilitating access to the HPC ecosystem, particularly for SMEs, and developing advanced digital skills; and

Independent and competitive HPC technology. To secure an independent and competitive HPC technology supply for the EU, including future computing technologies (such as quantum).

Beside ETP4HPC and BDVA associations, other key European stakeholders in HPC and data infrastructures (such as PRACE[e] and GEANT[f]) are also expected to collaborate closely with the EuroHPC JU to establish a leading-class HPC, data, and communication infrastructure in Europe.

The EuroHPC JU will also establish a wide consultation process to inform and involve interested European stakeholders who can contribute to the realization of the EuroHPC strategy. In particular, the contribution of the European computer science and software communities and the participation of large scientific and industrial HPC user communities will be fundamental to realizing the strategic objectives of European world leadership in HPC applications and development of a competitive HPC technology-supply industry.

EuroHPC JU Ramp-Up Phase, 2019–2020

The EuroHPC JU will need substantial investments in order to achieve its goals. In the period 2019 and 2020, the EuroHPC JU will invest €1.4 billion, of which €1 billion will be public and €0.4 billion will be private investments. The EuroHPC JU will acquire and install two top-five pre-exascale machines and several mid-range supercomputers by 2020 and support activities across the full European HPC ecosystem, including:

Develop a European microprocessor and European exascale systems. The European Processor Initiative (EPI)[g] partnership was recently established to implement a technology roadmap

a https://ec.europa.eu/digital-single-market/en/high-performance-computing
b https://eurohpc-ju.europa.eu/
c http://www.etp4hpc.eu/
d http://www.bdva.eu/
e http://www.prace-ri.eu/
f https://www.geant.org/
g EPI is coordinated by ATOS/Bull and brings together 23 partners from 10 European countries, gathering experts from the HPC research community, the major European supercomputing centers, and the computing and silicon industry, as well as potential scientific and industrial users with an additional specific emphasis on automotive applications; https://ec.europa.eu/digital-single-market/en/news/european-processor-initiative-consortium-develop-europes-microprocessors-future-supercomputers

for future European low-power microprocessors for extreme-scale computing, big data, and emerging applications with a specific focus on exascale HPC and automotive computing for autonomous driving. Taking a co-design approach, EPI will design and develop the first European HPC systems on a chip and accelerators. Both elements will be implemented and validated in a prototype system that will become the basis for a full exascale supercomputer based on European technology.

Develop exascale software and applications. Exascale software and applications and their integration in extreme-scale prototypes will help ensure EU leadership in the application of HPC for scientific, industrial, and societal challenges. These activities will support development, optimization (including re-design), and scaling-up of HPC application codes toward exascale computing, as in HPC Centres of Excellence[h] (CoEs). CoEs are also inherently committed to co-designing activities to ensure future HPC architectures are well suited for applications and their users, providing them with a high-performance, scalable application base.

Widen use of HPC and address the HPC-related skills gap. Widening the use of HPC and addressing the HPC-related skills gap will increase knowledge and human capital and boost HPC capabilities, including through creation of national HPC Competence Centres[i] and their networking and coordination across the EU. These competence centers can gather the necessary resources and expertise to provide a single local entry point for customized HPC services, ranging from, for example, highly specialized scientific and technical HPC users to SMEs with little or no experience in this domain.

EuroHPC JU in the Next EU Budgetary Period, 2021–2027

This is only the beginning, since in the EU's next Multiannual Financial Framework, covering the period 2021 to 2027, the aim is to continue supporting the EuroHPC JU via two different programs recently proposed by the European Commission—Horizon Europe[j] and Digital Europe.[k]

Horizon Europe is the EU's next Framework Program for Research and Innovation, the continuation of Horizon 2020,[l] supporting the HPC research and innovation agenda and addressing exascale and post-exascale technologies.

The European Commission is also proposing to support the EuroHPC JU via the Digital Europe program with an additional €2.7 billion. This will cover acquisition of exascale supercomputers (at least one with European technology in 2022/2023) and post-exascale systems (around 2027), including integration and deployment of the first hybrid HPC/quantum infrastructure in Europe; and actions to develop advanced HPC skills and further facilitate access to industry, academia, and public administrations to the HPC ecosystem, and more. The program will also exploit the synergies between HPC and other digital priorities, including artificial intelligence, cybersecurity, digitizing public-sector services, and digital skills.

Conclusion

The EuroHPC JU is an ambitious initiative that will enable European countries to coordinate with the European Union their supercomputing strategies and investments. We thus need to reduce the fragmentation of HPC investments across Europe and align strategies and investments that are key for European innovation and competitiveness. We need to secure access to world-class data and supercomputing facilities across Europe, ensuring development in Europe of an integrated exascale supercomputing capability accessible throughout Europe and covering the whole value chain, from technology components to systems and machines to applications and skills. This will avoid long-term negative effects on Europe's data sovereignty and scientific and industrial leadership and on Europe's place in the digital economy at large.

Today, the EU has put HPC very high in the political agenda, and we are confident this will remain the case for a long time. We are witnessing an exceptional surge of positive dynamics contributing to the success of the EuroHPC JU, including wide political support at both the national and EU levels, very strong support from public and private stakeholders, and the convergence of HPC with other critical disciplines for the data economy (such as big data and artificial intelligence). This is a unique opportunity for Europe to reap the benefits of mastering these converging technologies for our future. Only by joining forces can we mobilize substantial European and national efforts, both public and private, to place Europe in a leading position in the global digital economy.

Disclaimer. The views expressed in this article are the sole responsibility of the author and in no way represent the view of the European Commission and its services.

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h https://ec.europa.eu/digital-single-market/en/news/eu-funded-hpc-research-projects-and-centres-excellence-nutshell

i A national HPC Competence Centre is a legal entity established in a participating state that is a member state associated with the national supercomputing center of that member state, providing users from industry, including SMEs, academia, and public administrations, with access on demand to supercomputers and to the latest HPC technologies, tools, applications, and services, and offering expertise, skills, training, networking, and outreach.

j https://ec.europa.eu/info/designing-next-research-and-innovation-framework-programme/what-shapes-next-framework-programme_en

k http://europa.eu/rapid/press-release_IP-18-4043_en.htm

l https://ec.europa.eu/programmes/horizon2020/en/

DOI:10.1145/3312569

BY STEFFEN STAAB, SUSAN HALFORD, AND WENDY HALL

Web Science in Europe: Beyond Boundaries

AS WE FINALIZE this article November 11, 2018, and consider current and future directions for computing in Europe and across the globe, we remember the end of World War I exactly 100 years ago: the end to a war of atrocities at a scale previously unseen and the culmination of a series of events that European nations had allowed themselves to 'sleepwalk' into, with little thought for the consequences.[10]

When this article appears in spring 2019, we will remember the first proposal for a new global information sharing system written by Tim Berners-Lee 30 years ago at CERN,[4] the European organization for nuclear research. This proposal marked the beginning of the World Wide Web, which now pervades every facet of modern life for over four billion users. However, the Web 30 years on, is not the land of free information and discussion, or an egalitarian space that supports the interests of all, as originally imagined.[4] Rather, egotisms, nationalisms, and fundamentalisms freewheel on a landscape that is increasingly dominated by powerful corporate actors, often silencing other voices, including democratically elected representatives.

For seven decades Europe has been a political and social project, seeking to integrate what has been divisive historically and to make citizens more equal. While the proponents of the Web were driven by similar values, there is now increasing concern in Europe—and beyond—that the Web has become a vehicle of disintegration, polarization, and exploitation. What is more, since the Web operates at a global scale, beyond nation-states and with little formal regulation, we lack both the understanding and the means to avoid sleepwalking into another catastrophe.

Web Science seeks to investigate, analyze, and intervene in the Web from a sociotechnical perspective, integrating our understanding of the mathematical properties, engineering principles, and the social processes that shape its past, present, and future.[7] Over the past 10 years, Web Science has made remarkable progress, providing the building blocks to face the challenges described here. And yet there is more do to. In this article, we offer a more detailed definition of Web Science and outline its achievements to date. We consider how Web Science frames and addresses key sociotechnical challenges facing the Web now and for the near future, emphasizing the importance of this as new artificial intelligences start to shape the Web (and Web Science) in significant new directions. Arising from this, we outline some of the practical strategies Web Science is developing to integrate knowledge across disciplinary boundaries and build collaboration with Web stakeholders. Web Science equips us to understand the past and present of the Web and the skills and tools to shape a positive future.

What Is Web Science?

Web Science in Europe begins from the premise that the Web is both technical

IMAGE BY GRANDEDUC

and social. From this perspective, it is so difficult to disentangle the social from the technical that we describe the Web as 'sociotechnical.' The Web has been built on layers of communication at different levels of abstraction, from physical link layers (such as Ethernet) over Internet and transport layers (such as TCP/IP). It started as a Web of Documents (HTML), which served as the nucleus that other Webs would piggyback on: a Web of Data (RDF, SPARQL), a Web of Services (REST, JSON), a Web of Things.[a]

All these layers are defined by underlying technical standards and are the result of sophisticated engineering. And they are also deeply social, in two key ways. First, they have been developed in particular social contexts, with social goals in mind. For example, CERN was established to ensure a European nuclear capacity after the devastation of the research infrastructure in World War II.[13] Similarly, the original intentions for the Web were to allow physicists to share data across teams underpinned by an intellectual commitment that information 'wants to be free.'[8] Second, the Web merely offered a set of opportunities for humans to develop and populate information constructs and link with each other. Over time we have seen multiple and

a https://www.w3.org/WoT/

How do we engage the public in meaningful dialogue and decision making about the future of the Web?

competing rationalities drive the take-up of these opportunities. For example, information sharing and community building dominated academic and countercultural use in the early days. As new users began to embrace the opportunities on offer—for government and commerce in particular—content began to change. More than this, new users began to shape Web technologies—for example enabling user-generated content, video streaming, and secure online payments—in ways that, in turn, opened up new possibilities both positive, and less so.

The Web has changed the world and the world has changed the Web. And this is only set to continue, as the platform economy, the Internet of Things and new artificial intelligences offer new opportunities and shape the Web into the future.

For the past decade, Web Science has been building the interdisciplinary expertise to face the challenges and realize the value of this rapidly growing and diversifying Web. This task transcends the work of any single academic discipline.[7] While our universities continue—overwhelmingly—to be organized in siloes established in the 20th century, or much earlier, the Web demands expertise from computer science, sociology, business, mathematics, law, economics, politics, psychology engineering, geography, and more. Web Science exists to integrate knowledge and expertise from across fields, integrating this into systematic, robust, and reliable research that provides an action base for the future of the Web.

Evidence of our endeavors includes the networks of Web science labs, a number of undergraduate and postgraduate educational programs across Europe, summer schools on Web Science, and an ACM conference series.[b] We have understood how we may target to build 'objective' technology, yet end up with social stereotypes we wanted to avoid.[2] We have learned about the social and the technical processes that are needed to provide open data for the social good,[c] the methodological and epistemological challenges of using new forms of digital data and computational methods for social research,[15,16] and Web Science has progressed Social Machines that let us collaborate, yet work independently in distributed fashion.[23]

And yet there is much more to do. As a topical and critical example, we need to understand how the Web influences our democracies. Democracy builds on pillars like the representation of all, the rule of law, publicity and quality of information, temporality of decisions, and autonomy of individuals. The Web affects these pillars: online intimidation may threaten individuals and, silence them. Groups may organize online to ignore the law. Misinformation in echo chambers lowers the publicity and quality of information. In light of too much online transparency, compromises—which are vital in democracy—become infeasible. And, autonomy may be jeopardized by intrusion into private spheres. For all that, the Web continues to offer positive opportunities—voice to the otherwise silenced, connections between fragmented populations, mobilization of those who lack other means or are repressed—it is clear that these opportunities have come at a cost and—more broadly—that we may need to reconsider the pillars of democracy in digital society. These questions make Web Science more important now than ever. While Europe strives to respond to them in EU projects.[d] and various national endeavors thrive (for example, the Alan Turing Institute in the U.K. and, the German Internet Institute) we have only begun to face the challenges.

The Sociotechnical Challenges

There is nothing inevitable about the future of the Web. Its history to date has been made at the intersection of technical innovation and everyday practice with wider social processes and power relations, defying any prediction of fixed or finished outcomes. While this poses profound challenges—we cannot simply engineer the Web into a preferred state—we must develop integrated and in-depth sociotechnical understandings of the Web if we are to influence its future direction.

b http://webscience.org on labs, conference, educational programs and summer schools.

c https://theodi.org/

d For example, http://coinform.eu/

Here, we describe two key developments that characterize the opportunities and challenges we face.

Datafication refers to the development that our everyday activities are traced digitally at unprecedented scale and accuracy for commercialization and exploitation in a data economy. Datafication raises questions about how this situation can or should be managed and what might result out of its pervasiveness. The processes of datafication, their consequences and how we live with these are both social and technical. From the beginning, the question of what data is created depends both on human activities and technical devices.

How this data is used depends on configurations of ownership, markets, state authority, and citizens' rights as well as the technical affordances for circulation through technical infrastructures and the computational possibilities for analysis. To even describe the processes of datafication demands expertise of the highest level from computer science, law, political science, sociology, and more. To consider if and how society might respond to this new landscape likewise. What are the opportunities to flip data ownership from the big tech companies to the individuals whose data fuels the data economy? Engineering solutions, as developed in the SoLiD[e] project, may be part of the response, but how can we be sure that people even want let alone will have the capacity to use these solutions? What new challenges might these solutions pose? How would this impact on the underlying business model for the Web?

The digital divide. Web access continues to rise rapidly but over three billion people worldwide have no access, and 1:8 of the European population does not use the Web regularly.[f] We should avoid normative claims that the Web is 'good' for everyone, we know now that this is not the case, yet at the same time this should be a matter of choice not constraint. Further, beyond the question of access alone, we see an increasing divide between those highly skilled users who are able to derive the greatest benefit and those less skilled who are less knowledgeable about privacy risks, less able to protect their security and may derive less economic benefit from the opportunities available online.[17] So long as people are unaware of the technical mechanisms and social uses of datafication or the potential effects of this on their lives and life chances they will not be able to make effective choices about how to use the Web or join the public debate about the future of the Web. Web Science calls for new approaches to digital literacy, beyond the use of Web tools and beyond the extension of coding skills to schools (important as both these are) to build understanding of the Web as a sociotechnical system and drive toward greater empowerment of Web citizens. It engages, for example, through the Web We Want campaign, #fortheweb, and educational interventions.[11]

Both these examples are linked to wider practical, political, and philosophical questions. What are the checks and balances with regard to openness and privacy? What forms of transparency and accountability are appropriate and achievable, to balance individual privacy, fairness across social groups and a viable business model for the future of the Web? How do we engage the public in meaningful dialogue and decision making about the future of the Web?

Next, we investigate another most prominent sociotechnical challenge in more detail that today is most often characterized as a technical challenge alone, whereas it is deeply entrenched into the way that we as individuals or as society interact with each other and with the artifacts we create.

Web and Artificial Intelligence

The Web and its infrastructure has become interwoven not only with documents, but also with data, services, things—and artificial intelligences. Initially, the Web was a field of application for artificial intelligence. Knowledge-based systems and machine learning were used to provide intelligent access to information on the Web, to enhance search, to facilitate browsing or to negotiate in electronics market. In hindsight, this may be considered to have been a very useful, but a shallow, piecemeal interaction between Web and AI.

Yet since the end of its first decade, there was a vision to build a Web that was intelligent in itself, that included agents that would assist its users.[6] As this objective was beyond reach then, the Semantic Web community increasingly refocused on what became a proverb that data with *a little semantics goes a long way*. When researchers started to properly understand and use the social motivation of Web developers and Web content managers, some European researchers developed what now has become the two most popular Semantic Web applications, Wikidata[27] and Schema.org.[g] At the same time Web Science was coined as a field that would address the systematic understanding of these socio-technical interactions between Web and humans.[7]

At the end of the second decade of the Web, artificial intelligence took several major turns. Big data, which frequently came from the Web directly or from crowdsourcing on the Web, became the foundation for human-like performance on some tasks such as image annotations.[19] At the same time chatbots and virtual assistants have been developed and are now widely found on our PCs, smartphones, and in our homes. The latest developments let these virtual assistants acquire their knowledge from the Web, from archived dialogues,[12] or from live interaction.

Microsoft researchers were pushing the edge and put their AI chatbot "Tay" online to interact with and learn from human encounters. Humans quickly taught it to go *<<from "humans are super cool" to full nazi in <24hrs>>*.[h] While there was a wide discussion that the technology was inadequate, there seemed to have been little understanding that it was the social context and the social processes that determined the fate of Tay. While in the initial Semantic Web, the lack of such understanding led to a simple, but not very problematic non-adoption, in the case of Tay being an active agent the lack of

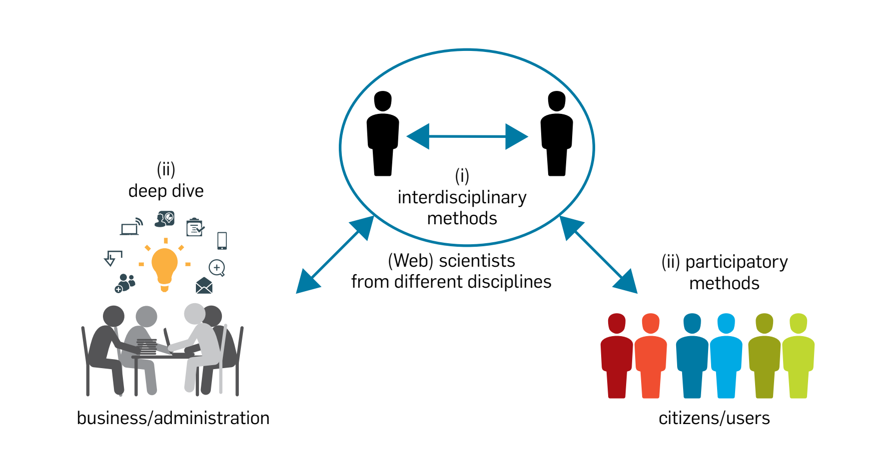
e https://solid.mit.edu/

f https://www.statista.com/topics/3853/internet-usage-in-europe/ref.

g Schema.org was an agreement of several search companies modeled after the preceding Yahoo! SearchMonkey system.[21]

h https://www.theverge.com/2016/3/24/11297050/tay-microsoft-chatbot-racist

Web Science methods must remain incomplete, if lacking interaction between scientists (i), or if not involving all of the Web's stakeholders.



insight led to malbehavior.

The Web as a social medium, whether considering past contributions or ongoing interaction, is prone to misguide artificial intelligences. Indeed, the question arises, what the social values are that an AI on the Web should embed and how this should be realized? Efforts to censor the successor of Tay by ruling out topics like religion and politics hamper the chatbot leaving it socially awkward.[25] Notions of social biases[2] and data representativeness are interwoven, but who decides whether or when the answers are 'right'? Several researcher communities (for example, Semantic Web, Computer-Human Interaction) and institutions have decided to actively tackle some underlying problems, for example, addressing the underrepresentation of women on Wikipedia by Edit-a-thons.

Finally, in two decades the Web has produced a range of highly valuable companies that did not play a major role before, or were not even founded when the Web started. Many of them benefit from first-mover and network effects that are difficult if not impossible to imitate by new companies. Will few big AI companies use their intellectual and computational power to rule the world using AI in the future? Or can society draw close, organizing the many and by sharing the necessary data and computation power bring AI to everyone's fingertips? The CommonVoice project[i] is certainly a project of developing AI on the Web in a direction that benefits more than a few of the already wealthy.

Extending Web Science

Web Science in Europe has begun the task of building up a body of knowledge to address these challenges. (Further information on the Web Science conference, educational programs and summer schools can found at http://www.webscience.org/.) Yet we have more work to do in extending Web Science, both within and beyond the academy. We classify the challenges by considering the interaction between various stakeholders involved, as illustrated in the accompanying figure.

Interdisciplinary methods. To the present day, the vast majority of Web research is disciplinary. Web Science in Europe has been at the forefront of developing interdisciplinary approaches to describing, analyzing and intervening in the Web. Our experience over the past decade shows that working across disciplines brings a depth of analysis and level of confidence in research outcomes that is much needed to address the very real challenges facing the Web—and society—as we move forward into the 21st century. Our experience also allows us to see where we can and should extend Web Science research through the novel application and development of research collaboration.

We are the first to recognize that this is challenging. Academic disciplines work with different objectives and have crafted a range of epistemologies, methodologies, and methods that have distinct professional standards. This is particularly noticeable across the computational and social sciences, where there are some profound differences in what counts as knowledge, science, and method. This is evident in the majority of—otherwise exciting—conferences between the social sciences and computer science, which tend to start from one 'side' or the other, and to privilege that body of knowledge, rather than opening it to revision and reconstruction through engagement from beyond.

Web Science has made the case for interdisciplinarity at a high level but transcending these established knowledge frameworks to build new understandings is difficult, demanding creativity, risk taking, and generosity.

One of many examples we may envision is the use of **interdisciplinary visual data analytics**. Web data offer remarkable potential to analyze the things that people say and do, in real time, over time, rather than the things that they say they do when asked using conventional methods, for example, interviews and surveys.[21,26] However, integrating understanding of the data and the computational methods required to interrogate this data with the domain-specific expertise required to address specific questions is challenging.[17] Furthermore, developing robust methodological understanding of the data and the effects of applying particular computational methods to this data is, as yet, in its infancy. While the visualization community in computer science harbors a wealth of techniques and tools to interactively explore data and find patterns, joint research work that would give Web scientists the means to 'interview' Web data and trace the impact of computational methods on results are lacking. Visualizations approachable and understandable across Web scientist subcommunities might become 'boundary objects' enabling different forms of expertise focus on the same phenomenon.

Another example is **participatory methods**. Much has been said about the ignorance of researchers about what the broad public wants, as well as about the ignorance of the broad public about what the scientists deliver. Let us consider the example of privacy protection. While the public's insight

i https://voice.mozilla.org/

into understanding implications of privacy issues may have been limited, one might have acknowledged that the public's attitude toward privacy protection did not only stem from lack of knowledge, but also from some nuanced degrees of willingness to share personal information. Such an ambiguous situation calls out for a two-way, participatory dialogue. Not content with only researching 'on' users, Web Science is committed to ensuring that the full range of voices is heard as we build our understanding of the Web and shape its future. Web Science seeks creative ways to build public understanding of the public about the threats, but also take on board, appreciate, and remark upon the personal values and attitudes of people. For instance, moral machines are one example where this is done now.[3] We are committed to developing participatory methods that allow us to build insight to diverse perspectives and to build dialogues between these. These methods may include: citizen science—where non-experts are included in a variety of research projects, for example, to study local communities[j] or to contribute subjective, possibly diverging, point of views;[1] online methods for deliberation; organizing face-to-face citizens' assemblies; and the use of AI techniques (for example, for enhancing knowledge and understanding of the Web and extending dialogue). It is a priority for Web Science that we observe these processes in action to inform continuous improvement in public engagement, for the benefit of policy making and, more widely, the engineering of the Web.

A final example concerns how we observe **the observers**. Powerful corporate or governmental actors may determine the fate of Web users observing what we do[22] and suggesting what we might do (or not), for instance, which accommodation to select, which job to apply to, or which person to befriend. Therefore, understanding what these actors do by tracking their activity and evaluating their algorithms has become an important activity. Researchers and NGOs like Algorithmwatch[k] pursue these tasks asking for data donations or crowdsourcing for getting insight into potentially discriminating or exploitative behavior. In other realms of life, corporate actors need to prove their carefulness by admitting to oversight of governmental agencies. In the Web we still lack such regulations, but the more that such actors become gatekeepers to our life, the less we can just rely on corporate slogans like "Don't be evil" (originally used in Google's corporate code of conduct).

j https://bit.ly/2SF8O1w
k https://algorithmwatch.org/en/

Conclusion

The Web has grown from an idea in 1989 to become the largest sociotechnical assemblage in human history in a little under 30 years. It is implicated in the lives, livelihoods, and life chances of over half the world's population already and connecting many more every day. While Europe embraces the Web and its opportunities for integration—perhaps more than other parts of the world—it discusses its risks of division. Rather than dystopian, and most likely false, predictions, what it needs is a scientific approach to understanding how the Web works and how it affects society. Web Science has been devised as a field to tackle these questions and we have highlighted a few aspects of where and how Web Science should proceed. In particular, computer science must look beyond its pasture and embrace the methodological experience and diversity by a broad set of fields—more than it has done until now. Funding and academic institutions need to welcome and reward such undertaking or it will not succeed.

Acknowledgment. This article benefited immensely from discussions we had with all the other participants at the Dagstuh[l] seminarl on "10 Years of Web Science: Closing The Loop." In particular, we want to thank Bettina Berendt, Fabian Gandon, Katharina Kinder-Kurlanda, and Eirini Ntoutsi.

l https://www.dagstuhl.de/en/program/calendar/semhp/?semnr=18262

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