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# UbiComp/ISWC 2019: A Post-Conference Summary Report

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**Abstract—The 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2019) took place from 9–13 September in London, U.K., colocated with the International Symposium on Wearable Computers. Meanwhile, the second UK Research Symposium on Mobile, Wearable, and Ubiquitous Systems (MobiUK'19) took place between 1st and 2nd of July in Oxford, U.K.**

■ **IN THIS CONFERENCES** column, we bring you not one but two recent events. The 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2019) took place from 9–13 September in London, U.K., colocated with the International

Symposium on Wearable Computers (ISWC 2019). Held in London this year, they attracted more than 680 participants and highlighted a total of 210 papers that featured a variety of recent technologies ranging from theoretical contributions to practical applications on ubiquitous and pervasive computing. Also in the South of England this summer was the 2nd UK Research Symposium on Mobile, Wearable, and Ubiquitous Systems.

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## UBICOMP/ISWC: SEPTEMBER 2019, LONDON

UbiComp/ISWC 2019 was initiated with two keynotes. Marta Kwiatkowska, a professor at the University of Oxford, presented the first keynote on modeling and personalization techniques and their roles in many applications such as medical devices, biometric security, and self-driving cars. In the second keynote, Lama Nachman, an Intel Fellow and the Director of Anticipatory Computing Lab in Intel Labs, discussed assistive computing, their experiences developing technologies for Stephen Hawking, and challenges in utilizing those technologies.

With 36 presentation sessions, workshops, posters, demos, and design exhibitions, UbiComp/ISWC 2019 covered a range of topics in the area of mobile, ubiquitous, wearable computing. In this paper, we describe exciting work in 1) health, 2) privacy, 3) haptics and kinetics, 4) user behaviors and mobile applications, 5) localization, 6) work, family, and society, 7) wearables, and 8) interaction paradigms.

### Health

A significant focus at UbiComp/ISWC this year was the impact and implications of computing for improving the physical and mental health of individuals, with particular emphasis placed on mental health. Indeed, one of the recipients of the distinguished paper award, “Assisted Medication Management in Elderly Care Using Miniaturised Near-Infrared Spectroscopy” by Simon Klakegg at the University of Oulu, showed that their system could sort pills with high prediction accuracy, providing high impact in the future. Two well-attended workshops were conducted during the first two days of UbiComp/ISWC 2019 to discuss state of the art research on detecting, preventing, and intervening in the mental health and well being of individuals. We cover one of these workshops here, together with a summary of three sessions from the main conference program.

The focus of the Mental Health and Well-being: Sensing and Intervention workshop was to discuss the issues and opportunities around using ubiquitous computing technologies for sensing and intervention in the mental health domain. Participants discussed projects such as measuring the effect of listening to music on

stress regulation and investigating the use of smart speakers for mental health monitoring. A common challenge identified by workshop participants was gathering accurate ground truth data, given that individuals or clinicians subjectively evaluate mental states. Other challenges in this space include explaining the output of machine learning models to clinicians, translating short research deployments into real-world impact via longer-term deployments or commercialization, implementing appropriate data privacy controls, and reappropriating commercial devices for research purposes. J. Simmons of the Social and Affective Neuroscience Program at the National Institute of Mental Health delivered the keynote address, discussing the priorities of mental health researchers and professionals and opportunities for collaboration with the ubiquitous computing research community.

Andrew Campbell (Dartmouth College) chaired the Mental Health session in the main conference programme. He opened the session by mentioning that UbiComp/ISWC research in mental health has advanced significantly over the past ten years, but has a long way to go before people can use it in their everyday lives. There was a common theme in detecting mental health conditions. These included stress, depression, and mood instability using unique features extracted from mobile data and the use of novel machine learning models. In addition, Wasifur Rahman (University of Rochester) presented interesting work on the diagnosis of posttraumatic stress disorder in refugees from Bangladesh using electroencephalogram signals.

The Mobile Health session chaired by Monica Tentori from CICESE focused predominantly on how interventions for healthcare can be delivered through mobile phones. Work presented by Woohyeok Choi (KAIST) and Peng Liao (University of Michigan) focused on unique ways of performing just-in-time interventions for health. Chia-Fang Chung from the Indiana University Bloomington discussed their work on the design of unique and personalized photo diaries to help individuals achieve their eating goals.

Presenters in the Wearable Health Sensing session chaired by Jakob Bardram from the Technical University of Denmark discussed using wearable sensors in health contexts. The majority of these

projects used machine learning to detect patterns in wearable sensor data that are associated with clinically relevant activities and symptoms. Catharine Tong from the University of Oxford discussed using a model to predict the fatigue and health status of Multiple Sclerosis patients using connected wellness devices, using weekly questionnaires as ground truth. The patients were able to use the devices as much or as little as they wanted to, which mimicked real-world usage but led to challenges in accounting for missing data during analysis. B. Teja Gullapalli from the University of Massachusetts Amherst presented a unique in-lab study investigating the relationship between cocaine-induced subjective states such as craving and electrocardiogram and respiratory features sensed via a chest band.

### Privacy

With increasing advances in ubiquitous computing, privacy must be taken into consideration. This year at UbiComp/ISWC, researchers developed new systems and tools for enhancing individuals' privacy, investigated new ways of identifying different privacy attacks, and discovered novel authentication methods.

Researchers highlighted the importance of creating more transparent, user-centric privacy-friendly applications. Xiaolei Wang from the National University of Defense Technology presented LeakDoctor, which determines if an application's privacy disclosure is essential for its functionality and, thus, protects users from unnecessarily disclosing sensitive data. Moreover, MobiPurpose presented by Haojian Jin from the Carnegie Mellon University (CMU) systematically classifies an applications' data collection purposes to help users understand why an application might want to obtain their private information. Finally, Mengwei Xu from Peking University presented DeepType, a paradigm that allows text input personalization to be performed privately on a user's local device, rather than on the cloud.

Identifying new ways that ubiquitous technologies can pose harmful privacy threats is critical for understanding our community's future directions with designing privacy-preserving ubiquitous systems. Tyler Giallanza (Darwin Deason Institute for Cybersecurity) highlighted potential

privacy threats for keyboard snooping on mobile phones. Swadhin Pradhan (University of Texas at Austin) presented REVOLT, a system that detects voice-replay privacy attacks on users of voice-based personal assistant devices. Likewise, Anindya Maiti (University of Texas at San Antonio) investigated how users' media consumption could be inferred through analyzing multimedia visualization techniques of smart lights.

Using biometrics for authentication was a predominant topic at this year's conference, as several systems utilized various biological factors for validating an individuals' identity. Daniel Hintze (Johannes Kepler University Linz) presented CORMORANT, a mobile authentication paradigm that incorporates biological and physiological metrics such as gait, voice, face, and keystroke dynamics to determine a user's identity. Other creative biological techniques for authentication included AcousticID, a system that uses gait information from acoustic signals for identification, and EarEcho, a wearable authentication device that integrates information from a user's ear canal echo.

### Haptics and Kinetics

The Haptics and Kinetics session showcased some novel interaction methods. A work of Erik Pescara (Karlsruhe Institute of Technology) on passive haptic learning described the learning of morse code without voluntary involvement of attention, focus, or motivation through a wearable haptic interface. Lawrence H. Kim (Stanford University) discussed a Vibration, Pressure, Shear (VPS) tactile display on the arm that can transfer the tactile information using a combination of vibration, pressure, and shear. Granit Luzhnica (Know Center) explained his latest work on boosting word recognition for vibrotactile skin reading through multiple user training methods. A novel input, output, and construction methods for custom fabrication of room-scale deployable pneumatic structures are given by Saiganesh Swaminathan at CMU. A work of Esther W. Foo (University of Minnesota) on garment-based dynamic compression discussed the user experiences of novel haptic applications. Kenichiro Shirota (Keio University Graduate School of Media Design) exhibited his research on exploring the shape change of pinna (i.e., the visible

part of the ear) for perception and illusion of sound direction change.

#### User Behaviors and Mobile Applications

As the ubiquity of smartphones increases, a large amount of data regarding user behaviors in both online and offline platforms has become available for the research community. UbiComp/ISWC 2019 featured a variety of novel research works, which investigate various user behaviors such as user's geographical mobility to mobile application (app) usage patterns.

One research direction is to understand users' navigational behaviors, which is vital to a large number of applications, ranging from effective recommendations to urban service planning. Amin Sadri from the Royal Melbourne Institute of Technology presented a new trajectory prediction problem, to predict the sequence of future locations (e.g., a trajectory in the afternoon) based on given historical data (e.g., a trajectory in the morning). Yan Zhang (Peking University) studied an interesting problem of route prediction for instant delivery and developed a design, which reduces the rate of the deliveries not finished in time by a huge margin. In addition, Young D. Kwon from the Hong Kong University of Science and Technology investigated users' reviewing behaviors exhibited both online and offline from which he proposed various features and significantly improved the performance of the churn prediction problem.

Studying how we can utilize large-scale data of users' app usages provides a fruitful research direction, which can enhance our understanding of users' behaviors. Mohammed Khwaja (Imperial College London) improved machine learning-based personality modeling by collecting mobile sensing data and self-reported Big Five traits from 166 participants in five different countries for three weeks. Jaejeung Kim (KAIST) investigated the effects and user experiences of different intensities of restrictive interventions (e.g., locking a user from using a smartphone). Zhen Tu (Tsinghua University) examined the feasibility of making personalized location recommendation by learning user interest and location features from app usage data. Likewise, Huangdong Wang (also Tsinghua University) proposed a new Bayesian mixture model to capture when,

where, and what apps are used and then predict future app usage.

#### Localization

Two sessions focused exclusively on localization were held at UbiComp/ISWC this year, with considerable attention paid to blending various technologies into more accurate and reliable localization apparatus.

Tao Gu (Royal Melbourne Institute of Technology) chaired the localization techniques session, which covered contemporary approaches to localization in a variety of contexts. Xinyu Tong (Shanghai Jiao Tong University) presented insights in improving localization efficiency for batch localization mechanisms to face the change of assumptions for the new paradigm. Indoor localization attracted much attention. Xuehan Ye (Renmin University of China) proposed a learning transition model for the floor mapping, while Huatao Xu (Shanghai Jiao Tong University) presented a holography-based approach to the radio-frequency identification (RFID) tagging and position estimation method. Huijie Chen (Beijing Institute of Technology) explored the crowdsourcing approach toward floorplanning as well as extracting both audio and inertial data.

Christos Efstratiou from the University of Kent chaired a session dedicated to optical approaches toward efficient localization. The session, localization with vision and light, consisted of four presentations discussing methods to combine light sensors, RFID, and computer vision for more accurate localization. Lin Yang from Noah's Ark Lab presented new sensors, which employ high-frequency modulation for obtaining visible light positions, with a deep neural network model for filtering the "invisible visual features" from the light. Zhongquin Wang from the University of Technology Sydney and Jingao Xu from the Tsinghua University approached indoor localization through blending computer vision and RFID tagging for increased precision, while Huanhuan Zhang from the Beijing University of Posts and Telecommunications developed a model for the recognition of unmodified lights.

#### Work, Family, and Society

UbiComp/ISWC has become the forefront of research within pervasive sensing and actuation

for alleviating productivity and accessibility in the workplace at home and within the society we live. This year's edition featured results from several important studies of integrating the Internet of Things (IoT), wearables, and interaction with mobile devices into one's daily life—and conclusively increasing the quality of life for relevant stakeholders.

In the UbiComp at Work session, Shayan Mirjafari at (Dartmouth College) discussed the methods of utilizing mobile sensing data from smartphones, wearables, and beacons to help study behavioral differences in low and high performing individuals in the workplace for in-time assessment and guidance in the workplace. Furthermore, Utku Günay Acer (Nokia Bell Labs) presented results from a real-world trial of 10 Belgian post employees that utilized wearable-based intervention to enhance the spatial coverage, response accuracy, and increase workers' engagement with crowdsourcing tasks. Finally, Mohit Jain (University of Washington) presented the work on designing conversational agents for user populations with limited literacy and technology experience, with results from an evaluative study with 34 farmers in India.

Hyosun Kwon from the University of Nottingham presented work on Connected Shower, an IoT device that captures water flow, temperature, and shower-head movement. The study concluded that sharing intimate data with service providers was acceptable if the data were sufficiently abstract and anonymized. The research threw light upon the challenges in the design of trustworthy data-driven IoT systems, and what needed to be warranted to be both acceptable into activities of our daily living. Anna Wojciechowska from Ben Gurion University of the Negev presented a model of how people understand drones based on their design and proposed a set of design guidelines for future personal drones. Finally, Timo Jakobi from the University of Siegen discussed a design case study of IoT at home, where the author equipped 12 households with do-it-yourself (DIY) smarthome systems for two years and studied participants' strategies for maintaining system awareness, from learning about its workings to monitoring its behavior.

A work of Ying-Yu Chen (University of Washington) on adoption barriers for technology for family mealtime found that parents prefer screen-based technology over voice interfaces and smart objects because parents perceive the latter two systems to intrude on their relationship with children. Anastasia Kuzminykh (University of Waterloo) discussed results from a multiphase study on a framework designed for parents to monitor their toddlers and school-age children. Concluding the Family and Technology session, Chuang-Wen You at the (National Taiwan University) presented SoberComm, a mobile support system that provides quantitative and qualitative evidence that the system enhances problem-solving skills and facilitates communication between alcohol-dependent patients and their family members.

### Wearables

Researchers in the UbiComp/ISWC focused on developing and exploring new ways of using wearables in many practical scenarios.

Researchers explored novel ways of interaction with embedded e-textile sensors. Flex-Touch, by Yuntao Wang (Tsinghua University), is a technique that enables long-range touch sensing for up to 4 m and object detection for distances up to 2 m. Phyjama, presented by Ali Kiaghadi (University of Massachusetts Amherst), explores how textile sensors can be embedded in loose-fitting clothing, such as sleepwear made from cotton or silk fabric, to monitor users' cardiac or respiratory rhythms. Similarly, Ruibo Liu (Dartmouth College) investigated how soft, conductive fabrics can infer joint rotational motion for physical rehabilitation purposes.

Existing wearable fitness technologies can make physical activity tracking in realistic scenarios difficult, and at times, inaccurate. Gino Brunner from ETH Zurich explored this concept in swimming by applying deep learning techniques with a smartwatch for accurate lap counting and style recognition in an authentic, uncontrolled environment. Likewise, Xiaonan Guo from Indiana University–Purdue University Indianapolis extended fitness trackers beyond the wearable device through developing a personalized fitness assistant system with only using WiFi. On a macro-level, Jessica R. Cauchard from Ben Gurion



University of the Negev presented an analysis of how different tactile and visual feedback in sports fitness technologies affected users behavior for future design implications.

#### Interaction Paradigms

Papers on new interaction paradigms mainly focused on new input methods for wearables and smartphones. Lik Hang Lee (Hong Kong University of Science and Technology) presented a novel one-handed thumb-to-finger input method for augmented reality head-worn computers, such as smart glasses while achieving better results than existing thumb-to-finger solutions. Zhican Yang at Tsinghua University explored a new way for activating voice input on smartphones by avoiding the need to press a button or using a wake word for activation. He presented ProxiTalk, a method that recognizes the user's intention when bringing the phone close to the mouth to activate speech input while only using in-built smartphone sensors. Moreover, Rushil Khurana (Carnegie Mellon University) proposed the concept of a detachable smartwatch that can be used as a wearable device depending on the context, such as for navigation when biking, game controller, or blindspot detector inside of a car. Juyoung Lee (KAIST) presented SelfSync, a concept of having the user move two body parts in synchrony to initiate communication with their computer and suggests two synchronous gestures by using wrists, leg, and head movements.

#### Looking Forward

Next year's UbiComp/ISWC 2020 will be held on 12–16 September 2020 in Cancun, Mexico. It will again be multitrack and include a broad multidisciplinary program.

#### MOBIUK: JULY 2019, OXFORD

The 2nd UK Research Symposium on Mobile, Wearable, and Ubiquitous Systems (MobiUK '19) took place from the 1st to the 2nd July 2019 at the Department of Computer Science, University of Oxford, UK. This year's symposium attracted 81 participants and featured 28 extended abstract submissions with subsequent presentations from total of 37 authors from universities across the U.K.

#### Invited Talks

Seven invited talks were given throughout the symposium, covering a broad range of research topics. First, Suman Banerjee from the University of Wisconsin-Madison kicked-off MobiUK '19 with a talk on "The Roaming Edge (in Smart Cities)," a mobile sensing platform on the edge deploying mobile sensors for transport analytics. Using their moving sensing platform Trellis, he shared how edge computing can cope with huge amounts of data collected via sensors in and on buses. Questions circulated around the challenges of integrating a third-party application ecosystem on the edge, the lack of situational awareness of sensors, and with regards to ethics, security, and privacy. Amanda Prorok from the University of Cambridge showed cutting edge results from her lab around trajectory planning for autonomous robots. In "When Robots Hit the Road: New Challenges in Multi-Vehicle Coordination," she discussed the challenges of coordinating robots including the creation of information flows for control components, how to incorporate communication, and achieve consensus for assignments. Prorok also talked about data obfuscation for increased privacy using a geo-indistinguishability approach. On the second day, Tanzeem Choudhury (Cornell University) gave the talk "Mindless Computing: Designing Technologies to Subtly Influence Behavior," which highlighted her lab's efforts in integrating technology seamlessly into our daily lives. For instance, dining plates with RGB sensors change color based on the color of food, influencing people to increase/decrease the quantity of food they serve. Discussions revolved around integrating environmental awareness into these technologies and their system's long-term effectiveness. The last invited talk by Romit Choudhury from the University of Illinois at Urbana Champaign was about multi-sensory in-ear wearable computing devices, describing new possibilities such as jaw motion or hollow earphones for better ear-care. His team built a prototype that moved the DSP outside of the headphones so that it can listen to noise much before it reaches the user's ear. They showed considerable decrease in noise levels compared to current Bose state-of-the-art headphones. The talk led to various interesting discussions about the future and challenges in building earable

devices, and the limitations of their current headphone model.

The remaining invited talks formed this year's industry session in which some of the sponsors shared new developments and projects with the research community. First, Markus Hoffmann from Nokia Bell Labs started his talk "Creating a Reality Beyond the Real" by describing his vision of a multisensory future, where use of technology is innate in our natural lifestyle rather than being a hindrance. In one such application, his team is working with Alex Thomson, a British yachtsman, to develop devices and a framework that can understand the state of our physical and mental well being without us having to actively interact with the device. Participants hinted at potential risks of integrated technologies collecting lots of personal data, voicing privacy concerns, and explored possible solutions, i.e., potential data ownerships via government regulations or technology hierarchies. Andrew Mundy from ARM discussed challenges and opportunities of running "Machine Learning on the Edge" in contrast to the central cloud. He emphasized that running deep neural net-based inferences on the edge are challenging due to its limited resources. The heterogeneity in edge infrastructure is another challenge as most are owned by multiple manufacturers running their proprietary APIs. Mundy mentioned that ARM is interested in leveraging the existing frameworks like TensorFlow, PyTorch to build solutions on top of it citing FixyNN as an example. Finally, Justin Philips from Google talked about "The Challenge of Continuous Heart Rate Monitoring from Wearables," where he described the mechanism used for monitoring the heart rate measurement (HRM) using Photoplethysmograph (PPG). The Google Fit platform has also integrated other device sensors like Inertial Measurement Unit with PPG to reduce the HRM error rate. The talk led to lively follow-up discussions to understand reasons of degradation in HRM quality, range of degradation, and how would skin color affect their technique?

#### Machine Learning

The presentations of the five paper sessions spanned a range of domains and themes with one major research trend around the theme of machine learning (ML) clearly prominent.

With a total of nine long and two short presentations, the theme of ML covered two sessions. Two talks covered issues around developing on-device deep learning with limited resources, e.g., memory constraint environments such as micro-controllers and mobile devices. One was presented by Javier Fernández-Marqués *et al.* and another by Valentin Radu. Other talks related to ML covered analyzing audio sensors for social sensing with the goal to identify speakers with only one smartphone by compressing audio that produces a compressed representation, which is able to recognize voices of known and new speakers. Applications envisioned by the researchers support for autistic persons to analyze their social interactions, but privacy issues still need exploration. Privacy was also discussed in an automatic data summarization methodology talk by Manousakas *et al.* that combined Bayesian coresets models and differential privacy to allow for scalable data analysis and the reduction of inference cost. Also using Bayesian models was the team of Gudur *et al.* proposing their Active-HARNet approach, which combines Bayesian deep learning with human activity recognition solving the issue of unlabeled data with only a few data points. Finally, Haoyu Liu from Edinburgh University presented an investigation of the security of Belkin Smart Home devices WeMo finding an exploit that allows for WiFi passphrase leakage making the devices vulnerable to phishing attacks.

#### Security and Privacy

The session on security and privacy included five talks: Dodson *et al.* conducted a longitudinal study of 50 000 Internet-connected industry control systems (ICS) without access control introducing a model to fingerprint unsecured, Internet-connected ICS (robotic arms, conveyor belts, pulps, etc.). During the discussion, the authors were asked if they know of tailored mass attacks, but most are initiated on traditional ways, e.g., Stuxnet. Vasile *et al.* highlighted other security issues around key authenticity in secure mobile messaging. Problematising how key management is not done by users alone, she explained how key serves are vulnerable to ghost user attacks. Their solution was an advanced notification system that gathers more contextual information such as

employing goshopping to establish trust and confirming keys automatically. Perez *et al.* explored if and how mobile devices can be traced and identified via their electromagnetic emissions. They experimented with two kinds of attacks. First, internal (app-based) attacks in which approximately ten data points were needed to identify single device with 98.9% accuracy. Second, external (proximity-based) attacks, which also resulted in the identification rate of single devices of 96.7%. Finally, N. Davies was talking about the design and implementation of an enhanced privacy mediator approach to privacy protection in IoT-rich environments combining mobile technology and Cloudlets.

#### Sensing—Algorithms and Applications

In this session, four long and two short talks were presented. Zhang *et al.* developed an approach, SensorID, to calibrate smart device sensors without the danger of uniquely identifying a specific device. Based on Gain Matrix Estimation and the sensor outputs, their approach produces globally unique fingerprints for iOS devices. It was pleasing to see a demonstration of research impact in SensorID—Apple have adopted their suggestion of adding noise and have also removed sensor access by default in Mobile Safari. Ferlini *et al.* provided insights of their work with Nokia Bell Labs on Multimodal Learning algorithms which enables in-ear hearing devices to leverage multiple inputs such as audio, head movements, eye movements, and so forth. They provide a real-time solution in a resource constrained environment in order to reduce the cocktail-party problem. Catherine Tong presented their team's work on ML to model the data from 198 Multiple Sclerosis (MS) patients' connected health and wellness devices (smartwatch, weighing scale, sleep tracker) to predict patients self-reported fatigue and health state scores for six months. Their solution is based on an ensemble of modality-specific AdaBoost regressors, which handles the issues of multimodal and missing data elegantly. Intarasirisawat *et al.* were tackling how to use game-based assessments for early detection of cognitive decline such as dementia. They integrated their solution into existing mobile games like Tetris, Fruit Ninja, and found that device touch (swipe speed, length) and

motion are significantly correlated with cognitive performance.

#### Mobile Data

This session consisted of four long and two short presentations. Powar *et al.* posed privacy-preserving data publishing as a risk management problem using the concept of linkability, which forms the basis of their novel threat modeling approach. He remarked that the dependence of their approach on the source of data has not been explored yet. Hasthanasombat *et al.* talked about how one can answer explanatory questions from mobile data, e.g., how the existence of a venue would affect footfall or health outcome in this area. They employ causal inference methodology to deal with the mobile data since it is observational in nature rather than coming from a controlled environment. Varvello *et al.* talked about how energy measurements can be performed on mobile devices with high accuracy exclaiming that currently both hardware- and software-based solutions have limitations in terms of accuracy or are expensive. Singh *et al.* described how people's mobile app usage habits are strongly correlated with the demography of the place. Their study found that urban areas are more dominated by apps like WhatsApp, Netflix, and blogging. By contrast, rural areas saw more traffic coming from background OS updates and streaming dominated by Windows phones. Participants enquired about their clustering approach and the use of mutual information metric.

#### Looking Forward

Next year's event will again seek to attract faculty, researchers, innovators, and students from all stages of their careers. The event will be chaired by Prof. Mirco Musolesi and take place at University College London on the 6th and 7th of July 2020.

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