Biometrics and AI Bias

I. Background: Physical Characteristics as Biometrics

WHILE humans share many physical characteristics, they are not replicas of one another in appearance. Despite their uniqueness, common features mean that comparisons can be made. The ability to identify someone by face has been one of the most fundamental ways that humans have connected with each other as distinct persons [1]. Recognizing someone is in fact a form of human visual information processing [2]. Long before mirrors were available in the ancient world (circa 5th century BCE the Greeks used hand mirrors for grooming [3]), descriptions of one's face were always determined by another's gaze or at best one's own description of their reflection in clean water illuminated by sunlight. Some even gained nicknames through the identification of distinct features on their forehead, nose, eyes, eyebrows, ears, and cheeks, for example, or through some clear markings, such as freckles or a birthmark. These were all the usual ways of remembering individuals; not as a means of discrimination but simply for the purposes of identification. In villages that did not exceed 250 households, it was possible to know of, and remember everyone [4], especially given that relations possessed similar and familial features.

Today, we refer to these distinct physical characteristics as biometrics [5]. We have used biometrics such as fingerprints to denote uniqueness since the turn of the 1900s (e.g., Scotland Yard introduced the Galton–Henry system of fingerprint classification published in June 1900 [6]). By the mid-1980s, U.S. law enforcement had automated fingerprint matching, and by the 1990s, 500 automatic fingerprint identification systems (AFIS) were used to convict people of crimes [7]. The implementation of AFIS marked the first time that automation had been used to cross-check minutiae. Presently, millions of minutiae have been gathered worldwide using high-resolution cameras, away from traditional ink-based methods (e.g., in India, the world's largest biometric ID system, known as Aadhaar, has systematically collected over a billion fingerprints). Interpol's AFIS alone has 220 000 fingerprint records from more than 17 000 crime scene marks, conducting 3000 comparisons a day [8]. Commensurately, it has only been in the last two decades that automated facial recognition has become possible and prevalent for a variety of applications, such as unlocking phones, locating missing persons, reducing retail crime, and even tracking student and worker attendance among other applications [9].

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II. Automated Facial Recognition Systems

Some of the earliest automated biometric recognition systems of the 1980s could be described at best as clunky. They required specialist stand-alone hardware with limited computational power, and algorithms that matched on a small number of given attributes with a limited record sample in their databases, compared to today's large number of attributes which contain, in some cases, billions of images [10, ch. 6.5]. Consider the face, as an intricate map of which distinguishing features are registered and compared with other records in a database [11]. Biometrics measure distinctiveness, seeking variations in biometric patterns among the general population. The higher the distinctiveness of a feature, the more unique the identifier to the individual [12]. Thus, facial biometrics relies on spatial geometry to denote measures of key features of the face.

Automated facial recognition systems are broadly comprised of four stages: 1) face detection (e.g., through the use of CCTV footage); 2) face analysis (2-D and 3-D captures are possible, although most captured images are typically 2-D, with 3-D predicted to have a significant impact in the future); 3) image to data conversion (using a very complex mathematical formulae); and 4) comparison and matching [13]. It is in the second stage where measurements are taken of the distance between the eyes, from the forehead to the chin, the cheekbones, contours of the lips, ears, and chin, in addition to the depth of eye sockets [14]. The aim of this analysis is akin to finding distinct points of interest on a map, where each facial image is converted into a faceprint (a unique profile of 1s and 0s). When a faceprint is compared against a large database of other faceprints, statistics are used to glean which "near matches" might be worth considering for further investigation and scrutiny [15].

Statistics have always played a key role in identifying approximate biometric matches, where a given match on a "hit" (i.e., a suspect) was required in resolving a criminal investigation [16]. Low-resolution surveillance footage was at times the only available evidence for the police near a crime scene, especially when the suspect was not previously known to authorities. Very low-light levels, off-angle, atmospheric conditions (e.g., rain or fog), and other camera noise [17] also add to the complexity of using photographic evidence to make a conviction or even an arrest. Digital facial images are rarely used on their own, without direct eyewitness evidence. However, in the absence of eyewitness accounts, CCTV footage may well be the only available data to bring a criminal to justice, especially in the context of a heinous crime where the use of automated biometric recognition is deemed proportional to the crime committed. Today, firmware updates have added capabilities to even the lowest resolution surveillance camera systems making them more "intelligent" [18], through advancements in deep learning algorithms based on neural nets, in addition to increasing levels of interconnectedness over the cloud allowing for image sharing at scale [19].

Biometrics vendors increasingly tout an impossible "near 99%" exact facial image case match, claiming to utilize the additional capability of Web scraping (of images) from the Internet, social media platforms, and more to enhance their results [20]. But does more data necessarily mean better outcomes? It all depends on the quality of the data gathered and of the data matched against. The possibility of entangling innocent people in suspect lists and even wrongful arrests [21] is higher than ever before, as a result of the connected nature of social networks and Internet-based traffic. If I exist and have presented in a public space (physical or online), then the chance that my face will be stored on the cloud is not only high but inevitable, whether or not I have granted consent for that image to be collected and retained [22]. However, there are also reported benefits; that is, this very ability to match against public images has provided a fresh avenue to solve crimes in a manner that accounts for individuals who are not on criminal databases, and would never have otherwise come to the attention of authorities via a match [23].

III. Citizen Rights, Public Spaces, and Informed Consent

But what is the cost of increased biometric data collection in public spaces? Here, we are not referring to the cost of upgrading an aging surveillance camera or other operational costs, but rather the human cost with respect to innocent people presenting on suspect lists via dragnet-style facial recognition searches [24]. To date, a number of U.S. cities [25], including Boston, Portland, and San Francisco have moved to ban facial recognition systems in their neighborhoods as a means of addressing human costs. From an organizational perspective, the State of Illinois has banned the corporate use of biometrics systems through the biometric information privacy act (BIPA) [26]. The matter of appropriate regulation surrounding these biometric systems has now become part of major legal and policy debates throughout the world [27]. For example, see the recent bill introduced by U.S. Senators Wyden, Booker, and Clarke, known as the "Algorithmic Accountability Act of 2022". How to maintain one's privacy despite the automated process of data gathering and collection of facial images, is a question that must be addressed [28], [29], [67]. "Who owns information?" as Ann Branscomb asked in 1994 [30], has taken on new meaning since the advent of Web 2.0, 5G mobile, advances in storage area networks and new ways to analyze the data collected through emergent approaches in artificial intelligence and machine learning (ML) [68]. Soft biometrics, which provides an additional layer of description, can also infer a great deal about someone using qualitative attributes, by capturing data about the way an individual might style their hair or wear a beard; use hats, scarfs, or eye glasses; and even capture data about their attire including the type, brand, and color of clothes; the make-up applied; other apparel adorned such as earrings and necklaces, and much more [31].

As greater urbanization occurs toward the formation of megacities, smart cities development through digital transformation will also continue to evolve, as will the ability to collect additional data relevant to individuals through Internet of Things (IoT)-based systems and other related infrastructure. The ability to uniquely identify a person, by their face or gait, and even determine their probable emotional state simply via their facial expressions [32], will almost certainly give rise to a myriad of new emerging capabilities without the use of a token, and most likely without informed consent. Facial and musculoskeletal images have been scrutinized for decades in the early diagnosis of medical conditions, such as Turner Syndrome [33] and Noonan Syndrome, in addition to more recent attempts at detecting schizophrenia [34] or even for diagnosing whether someone is on the autism spectrum [35]. The extension of this, facilitated by the identified technological developments, is evident in a range of contexts. For instance, employers can now analyze worker moods and even remote productivity through a variety of biometric data they gather via specialist software on company laptops and other proximate devices [36], [37].

IV. Machine Learning and AI Bias

Digitalization and datafication processes are not new. The world has been gradually undergoing digital transformation, especially since the introduction of transaction processing, enabling data to be entered and stored as records in databases that could be used for report generation and inquiry processing activities. Today, as big datasets have been amassed by corporations, government and law enforcement agencies, ML is increasingly being utilized. ML is the process by which software can automatically detect matches, meaningful patterns and trends in large troves of data (e.g., facial images). It also allows for the automatic detection and verification of a face in a biometric image search. But identifying people by the way they look is not as simple as it might sound [38]. People change over time, either through the natural aging process or by changes in fashion (including hair cuts, facial hair, make-up, clothing, and accessories) or other aesthetic changes like plastic surgery [39], [40].

Increasingly, high-quality images such as those found in driver's license state databases and passport photographs have been utilized by government agencies for identity matching, for example, in bushfire situations in Australia [41]. But there is still a considerable proportion of the population that do not drive and have never traveled overseas. This results in numerous questions that require exploration, such as what happens to people who have neither credential? And how will a person be treated if found to be an exception? There are also questions surrounding how many matches may be returned in given search algorithms in the context of verification versus identification (i.e., an alleged one-to-one match as opposed to a one-to-many match of an unknown person with an established identity in a government database). Similar challenges arise in other applications of AI in diverse contexts. In the workplace, for instance, facial recognition is becoming more evident, especially in candidate matching and recruitment. AI-backed platforms such as Paññã (https://www.panna.ai/)

enable companies to process video content such as online interviews to determine whether a candidate is potentially cheating by reading a script or listening to cues from someone off-screen. These algorithms look for aberrant behaviors based on eye movement, facial expressions, and more. However, prevalent questions arise in this scenario, such as: is there adequate diversity in the original training dataset to capture and interpret facial expressions of people from diverse cultural backgrounds? Can the algorithm capture the complexity in the environment, for example, in cases where the interview is held in a noisy or public space? Hence, any potential biases or limitations in the algorithms can result in the misinterpretation of behaviors, potentially leading to discrimination.

Recognizing the many limitations of ML and the hidden assumptions pertaining to "the dark side" of AI [66], as well as traditional challenges related to biometrics, is critical. For example, false acceptance rates (FARs) and false rejection rates (FRRs) are still common in biometric systems [42]. This begs a series of additional questions: should we be automating critical service provisioning utilizing technology in this way (e.g., for emergency patient identification)? What is the role of ethics in these situations, specifically in relation to privacy, autonomy, informed consent, and responsibility? Is it possible to think of a future smart city, where an elderly person who might be wandering in the early stages of dementia, can be reunited with family or their caregivers if found roaming through multimodal gait and facial analysis? And what are the implications in view of algorithmic bias?

In the context of this special issue, the bringing together of facial image datasets and AI-based algorithms has been determined to lead to a variety of algorithmic biases "in context," including racial bias [43] and gender bias [44], although not all biases are demographic in nature [45]. Algorithmic bias occurs when "AI produces systematically unfair outcomes that can arbitrarily put a particular individual or group at an advantage or disadvantage over another" [42, p. 2]. Facial recognition systems in particular struggle with skin tone [46], gender identification, and many other attributes. Certain communities are discriminated against either because too much training data exists on that community historically, or not enough. This is an endemic issue in the original training dataset that has been collected, without adequate testing for sample representation [47], or even specified data annotation. Yet again, key questions are often left unanswered, such as what is the source of the data being used? When was it created? Who generated it? For what purpose? What does it mean? Akter *et al.* [48] went beyond mere "data," to describe three primary dimensions of bias that might pervade ML inclusive of design bias, contextual bias, and application bias, identifying subdimensions that are highly applicable to biometrics, such as model, method, cultural, social, and personal biases. Some of the most controversial research to be conducted to date perhaps [66], as pointed out by Bowyer *et al.* [49] is proving "criminality" by facial image [50]. This may well be considered the most extreme form of bias, to imagine that one's face can denote their criminality, or whether they would make a good rental tenant.

In order to ameliorate the risk of AI bias in biometric systems, algorithmic audits can be conducted to ensure algorithmic justice [51], [65] through comprehensive testing and validation, dependent on the choice of the algorithm used, which is very much linked to the application context. This will ensure that inclusivity and equity are addressed in discussions and decision-making processes. Racial bias, and gender bias, are prevalent in many commercial and government biometric systems and a number of nongovernment organizations (NGOs) are attempting to raise awareness of these problems. For example, the Algorithmic Justice League https://www.ajl.org/ that seeks to "build a movement towards equitable and accountable AI" [52]. Two seminal works that sparked numerous movements and raised awareness about biases in ML and their corresponding social implications included Cathy O'Neil's (2016) *Weapons of Math Destruction* [53] and Safiya Noble's (2018) *Algorithms of Oppression* [54]. Overcoming such AI-biases in biometrics requires diversity in the workplace; greater depth of testing and validation in the AI design, AI dataset, and AI model; a thorough assessment as to whether the application context is appropriate for use; and an awareness of emergent research and developments pertaining to the design of AI-based systems.

V. Areas of Future Research

There are many promising research areas relating to the design of biometric systems and ML algorithms to alleviate AI-biases. One such area is relevant to gender bias, where emerging evidence indicates that the overrepresentation of males in the creation of AI systems during the design phase leads to biases creeping in. This, in turn, impacts usability and engagement with this technology in inequitable ways, leading to further perpetuating learning, working and living spaces that disadvantage women [63]. While there is recognition that algorithmic justice can only be achieved through inclusivity in design of AI systems through participatory design processes, research and practice are in nascent stages with regard to achieving this goal. At a time when AI is transforming the way we engage with the world of work and play, it is crucial that researchers engage with narratives from women as leaders, consumers, users, and designers of technology [69]. The issue of pipeline block is well examined in gender studies, with substantive studies focusing on strategies at institutional and individual levels that are transforming women from engaged players to empowered change agents. There is an opportunity here for AI researchers to draw on this preliminary research on women and leadership and pipeline block [60], [64] to examine the biases that impact women's participation as equal players in the design process. For example, gender research indicates that particular forms of capital are valued in traditionally male dominant spaces, which advantages the dominant cohort, leading them to repeat the cycle of creating enabling contexts that attract and retain those who embody male prototypical capital [58], [59], [61]. Capital is defined by Bourdieu as "all goods, material and symbolic, without distinction, that present themselves as rare and worthy of being sought after in a particular social formation" [55, p. 78]. There is a need for a critical theory perspective to examine the kinds of capital (e.g., cultural and social psychological) that are valued in the design process, who the key players are, what the rules of the game are and what kinds of capital needs to be mobilized to achieve legitimacy.

While there is acknowledgement of gender bias in ML in research and practice, the body of knowledge is still very much in its early stages, with no known research yet on capital that is valued or the factors that impact capital creation processes in technology design. Given that capital creation processes are impacted by factors at micro, meso, and macro levels, there is also a need for taking a holistic and multistakeholder lens to advance gender theory in AI. Specifically, there is a need for examining inclusivity in AI that acknowledges divergent stakeholder interests and takes an interdisciplinary and complete view of the ecosystem of AI design through focusing on endogenous and exogenous factors. In particular, research can draw on the factors impacting emergence and enactment of leadership among women in AI by drawing on related literature in women and leadership [56], [57], [62] to develop theory and practice that support the advancement of women's careers in AI. Furthermore, additional biases identified throughout this editorial require equal and detailed consideration, from the perspective of design.

VI. Overview of Accepted Papers

Four papers are featured in this special issue on "Biometrics and AI Bias." The first paper by Katsanis *et al.* brings together ten coauthors and is titled: "U.S. Adult Perspectives on Facial Images, DNA, and Other Biometrics." This is a timely piece that will contribute to existing scholarship empirical evidence required to inform policy debates, depending on the level of sensitivity of given communities. The authors were supported in this work in part by the National Institutes of Health (NIH) Office of the Director (OD) and in part by the National Institute of Dental and Craniofacial Research (NIDCR) under Grant 3R01DE027023-04S1. The work of Katsanis was also partially supported by the National Human Genome Research Institute (NHGRI) under Grant R01HG009923, and the work of Cook-Deegan was supported in part by the National Cancer Institute under Grant R01CA237118 and Grant U01CA242954. The project team of Katsanis, Claes, Doerr, Cook-Deegan, Tenenbaum, Evans, Keun Lee, Anderton, Weinberg, and Wagner is cross-disciplinary, with backgrounds in health, medicine, engineering, genetics, technology and innovation, biostatistics, law, and bioethics. They also have diverse employment in hospitals, academia, private enterprise and specialist centers.

The team explored the application of biometrics in the U.S. with an emphasis on facial recognition and DNA identification. Citing their substantial survey of over 4000 adults, they explored six types of biometrics; the level of comfort of applying biometrics to distinct scenarios; trust and responsible use of two types of biometrics; the level of acceptance of facial images in given scenarios; and finally, the perceived effectiveness of facial images for particular tasks. The study did not find sociodemographic factors to influence perspectives on biometrics in obvious ways, underscoring the need for qualitative approaches to understand the contextual factors that trigger strong opinions of comfort with, and acceptability of, biometrics in different settings, by different actors, and for different purposes. The team believes that these factors may well provide the information needed for the development of appropriate policies and oversight.

The second paper is titled, "A Comprehensive Study on Face Recognition Biases Beyond Demographics." The paper was written by Terhörst, Niklas Kolf, Huber, Kirchbuchner, Damer, Morales Moreno, Fierrez, and Kuijper. The eight authors were supported in part by the German Federal Ministry of Education and Research and the Hessian Ministry of Higher Education, Research, Science and the Arts with their joint support of the National Research Center for Applied Cybersecurity ATHENE, and in part by the Projects BIBECA under Grant RTI2018-101248-B-I00 MINECO/FEDER and PRIMA under Grant H2020-MSCA-ITN-2019-860315. The authors are from several organizations and institutions, the Department of Smart Living & Biometric Technologies, Fraunhofer Institute for Computer Graphics Research in Germany, and the Interactive Graphics Systems Group at the Technical University of Darmstadt. Morales Moreno and Fierrez are with the Biometrics and Data Pattern Analytics Lab at the Universidad Autonoma de Madrid in Spain.

Following on from the work of the first paper in this special issue, these authors now cast our attention to the use of face recognition systems and their growing effect on critical decision-making processes. The authors of this second paper maintain that while facial recognition solutions show strong performance differences, what is necessary is trustworthy facial recognition technology. In essence, this team embarked on analyzing the effect of 47 attributes implementing two popular facial recognition models (i.e., FaceNet and ArcFace), using the publicly available MAAD-Face1 annotation database that was based on VGGFace2, consisting of over 120M high-quality attribute annotations for 3.3M face images. The results of the study demonstrated that many nondemographic attributes strongly affected recognition performance, such as accessories, hairstyles and colors, face shapes, or facial anomalies. Plainly, the study showed that further research is required to make facial recognition systems more robust, explainable, and fair.

The third paper was an interdisciplinary effort by Dancy of the Computer Science Department and the Critical Black Studies Department at Bucknell University, alongside Saucier, the Chair of the latter department. Their paper titled: "AI and Blackness: Toward Moving Beyond Bias and Representation," hones in on "color" as an attribute as noted by the second paper in the special issue. Dancy and Saucier argue that AI ethics must move beyond the concepts of race-based representation and bias. The authors state that there must be further probing on the impact of facial recognition systems, and how they are designed, developed, and deployed. They state that while recent discussions have centered on racial bias caused by AI systems, we must go beyond the ethical considerations of bias and seek to focus on the examination of the ontological space that provides a foundation for the design of AI systems. This means that we need to consider the sociocultural contexts from the outset if we are to have any hope in creating systems that do not discriminate. The authors provide evidence for their argument by auditing an existing opensource semantic network called ConceptNet.

The fourth and final paper in this special issue is from Parra and Gupta from Florida International University, and Dennehy from Swansea University. This paper addresses the racial bias as in the case of the third paper written by Dancy and Saucier, and also introduces the concept of gender bias. While the first paper in the special issue used surveys, the second paper applied two models to 3.3M facial images, and the third paper audited the opensource semantic network called ConceptNet looking specifically at racial bias, this final paper used a scenario-based survey issued to 387 U.S. participants to explore when individuals in given daily life circumstances would be more likely to question the racial bias and gender bias in the context of AI-based online recommendations.

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