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From language to algorithm: trans and non-binary identities in research on facial and gender recognition

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Abstract
We assess the state of thinking about gender identities in computer vision through an analysis of how research papers in gender and facial recognition are designed, what claims they make about trans and non-binary people, what values they espouse, and what they describe as ongoing challenges for the field. In our corpus of 50 research papers, the seven papers that consider trans and non-binary identities use questionable assumptions about medicalization as a measure of transness, about gender transition as a linear and bounded process, and about the concept of gender deception. Otherwise, non-normative gender identities are absent and their consideration is in fact hindered by prevailing research values, particularly deeply embedded ones such as performance and accuracy. We point out how the use of shared datasets calcifies binary conceptions of gender. In the way that the field of computer vision conceives of ongoing challenges for its research, it does not yet face questions that trans and non-binary user experiences pose and often falls back on biologically essentialist notions of sex classification. We make two recommendations: that computer vision researchers undertake interdisciplinary work with researchers who study gender as a socio-cultural phenomenon, and that journal editors and conference organizers do the same in peer review and conference acceptance processes.

Keywords Gender recognition · Computer vision · Trans and non-binary gender identity · Discourse analysis · Machine learning · Artificial intelligence

1 Introduction

The technological drive towards ever more detailed applications of facial recognition and gender identification software has been relentless. Recently, high-profile public discussion has highlighted the anti-democratic potential of state and commercial forms of surveillance via facial detection and gender recognition. In Canada, where we work, police forces in the cities of Toronto, Edmonton, and Calgary have been under fire for their use of facial recognition software. A spokesperson for the Canadian Office of the Privacy Commissioner has commented that facial recognition has "the potential to be the most highly invasive of the current popular biometric identifying technologies" [1]. There are repeated calls from researchers for a moratorium on governmental and commercial use of such software and for strong oversight over how the technology is allowed to progress [2, 3]. Among the human rights that are the focus of such discussion are the rights of people who are trans, non-binary, agender, or gender nonconforming. Facial recognition software overwhelmingly maintains a binary and immutable conception of gender. In doing so, facial and gender recognition products and approaches override trans, non-binary, agender, and gender nonconforming identities by slotting people into wrong identity categories. This practice has wide-ranging implications and causes serious damage to trans and non-binary lives; in the hands of law enforcement in particular, facial recognition tools are "dangerous when they fail and harmful when they work" [4]. Before application of facial recognition software comes the development of approaches, techniques, and algorithms. It is to this research that our project turns its attention. We investigate the question of whether there is any consideration of trans and non-binary identities when researchers develop facial and gender

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recognition algorithms and, if there is, how these identities are conceptualized within algorithmic approaches. Through our analysis, we arrive at practical suggestions for research practices in the field of computer vision. We call for greater interdisciplinarity in gender recognition research, with a particular commitment to collaboration with fields engaged in the critical study of gender as a socio-cultural phenomenon.

The range of approaches to facial and gender recognition, in the field as a whole and in this analysis, is wide. In the words of Nikki Stevens and Os Keyes, "the technology consists of a shifting web of programmers, algorithms, datasets, testing standards, formatting requirements, law enforcement agents and other operators and users, and consequently, a shifting form" [5]. There is an urgent need to regulate the development and use of facial recognition software with a consistent focus on participant consent and research ethics in its development and on democratic and human rights in its application [4, 6–8]. In addition to the regulation of facial recognition applications, research and development of computer vision software lacks a theoretically informed grasp of identity characteristics and their human rights implications. In this regard, discussion of gender recognition within facial recognition research exhibits a severe lack of sophistication and foresight. This lack manifests itself in different ways and at different points—one of them is the way publications in facial recognition research are written.

We assess the ethics of thinking about gender identities in computer vision research through analysis of how studies in gender and facial recognition are designed, how they use language in their publications, what claims they make about questions of gender identity, and how (if at all) they link themselves to relevant discussion in the fields of gender and trans studies [9]. Given the overwhelming assumptions of binary and immutable conceptions of gender which have been shown to lie at the heart of most technological work on gender recognition [10], we ask: how do trans, non-binary, or gender-nonconforming identities figure in the research discourse of computer vision? What language is used to characterize the challenges and opportunities that trans, non-binary, or gender-nonconforming identities pose for facial recognition research and technology development? What does that language tell us about how projects of gender recognition situate themselves within the landscape of existing research on gender identities as well as the varied experiences of trans, non-binary, and gender-nonconforming people in their relation to technology?

1.1 Trans studies criticism of facial recognition research

In the history of trans experience and, with it, in trans studies scholarship, questions of agency and self-determination in relationship to gender performance are paramount. One of the foundational principles of contemporary trans studies is to listen to trans people "theorizing themselves for themselves" [10]. Such theorization brings with it new terms and ongoing revision of existing terms relating to trans, non-binary, and gender-nonconforming experience. These terms serve to not only nuance and differentiate for the sake of research, but—more importantly—to enable safe and nourishing ways of experiencing, living, and creating gender for current and future generations of trans, non-binary, and gender-nonconforming people. In that spirit, conceptual work in trans, gender, and queer studies persistently pushes back against wrong, harmful, and pathologizing conceptions of trans and non-binary lives. It is not an overstatement to say that to keep people alive is one of the desired implications of such research, conceptual work, and attention to language.

Experiences of exclusion, harm, and violence are repeatedly described and anticipated by trans, non-binary, and gender-nonconforming people when it comes to uses of facial recognition software. In the North American blogosphere, LGBTQ+ scholars, activists, and allies have been mounting vocal criticism of the technological drive towards facial recognition and gender identification software [11–16]. Concerns and first-hand complaints have been expressed about the use of facial recognition at airports impeding trans people's ability to travel, about such software denying trans people entry into gender-specific spaces and communities, and about the accumulation of stress and humiliation in trans people's lives when their identity is not recognized in daily, technologically mediated encounters. As Oliver Haimson et al. state, being trans "brings up many challenges because technologies are generally not created with the intention of including trans people and supporting their experience" [17].

There is now a range of critical scholarship at the intersection of trans studies and computer science. This critical attention is driven by researchers in studies of technology and human–computer interaction, researchers who consistently challenge the underlying conceptions of gender which inform this software and these approaches [18–21]. Jennifer Rode's work on "A Feminist Agenda for Feminist HCI" has had a formative effect on research that focuses on trans identities in human–computer interaction [19]. She proposed the concept of gender sensitive design as enabling necessary flexibility in the co-construction of gender and technological identity; and she calls for viewing gender as an integral part of lived experience, including in the relationship with technology. Ari Schlesinger, W. Keith Edwards, and Rebecca E. Grinter also work from the premise that identity categories, including those related to gender, are crucial in developing an expansive, intersectional conception of the "user" of technology. They advocate moving away from the user as a "rhetorical cipher" toward recognizing users as "individuals with complex feelings, motivations, and identities" [22]. In their corpus study of 140 CHI manuscripts that discuss

identity categories, they found 70% included gender as a focus, while only three manuscripts referenced transness and none used the words genderqueer, gender fluid, LGBTQIA, or queer [22].

Highlighting how notions of identity are "essential to trans individuals' health," Alex Ahmed modulates Rode's approach for a study of the relationship between trans identities and technology [23]. Ahmed asserts that "the design of interactive systems has been complicit in promoting harmful and essentialist gender roles" [23]. As a correction, she posits "trans competent interaction design" [23]. HCI should not merely "allow" trans people to exist but instead engage in trans advocacy by acting on the following insights:

1. design decisions may uniquely affect or disproportionately harm a trans person due to the ways we exist in and interact with the world;
2. interaction designs should be aware of this fact and willing to change their practices…;
3. interaction systems, design artifacts and academia as a whole can actively work to subvert cissexism, address the material concerns of trans people, and uplift our narratives and voices. [23]

Ahmed's study exemplifies that technology does not need to be geared specifically toward trans people to achieve these goals—the users she interviewed also discussed how social media and communication technology was "an important source of affirmation, information and connection" [23]. However, as Foad Hamidi, Morgan Klaus Scheuerman, and Stacy Branham have found when interviewing trans and non-binary individuals about gender recognition software more specifically, their participants reported that this particular technology did not offer any benefit to its users, was non-consensual, and resulted in automatic misgendering that was "perceived to be more harmful than being misgendered by another person" [20]. In other words, gender and facial recognition software is experienced as uniquely and perpetually harmful among trans and non-binary people.

In an analysis that spanned 58 papers across 22 years in top-ranked journals of the field, Os Keyes investigated what concept of gender was present in research on automatic gender recognition [10]. Keyes asked, how does the technology, as it is designed, "wrestle with the concept of gender," how does the research "operationalise gender and contextualise any gendered assumptions of AGR software?" [10]. The papers Keyes investigated treated gender as binary 95% of the time and as immutable 72% of the time. Research and design of technology must engage with trans people and their experiences. Particularly, it needs to take seriously the "resignation about their lack of agency" that trans and non-binary technologists express in relation to facial and gender recognition projects [20]. More generally, it needs to create roles for trans people and gender studies scholars in the processes of planning and carrying out research, making decisions, and creating designs so as to enable forms of affirmation and connection that are essential to trans and non-binary people's participation and well-being in everyday interactions with technology.

1.2 About our corpus analysis

In our analysis, gender is the central concept that binds together user experience, software design, and research activity. While some research fields have decades of experience in critical study of conceptions and expressions of gender, others have none at all. What is the relation between the gender conceptions held in research on gender and trans studies and research on gender recognition software? Commercial development of facial recognition software interacts closely with research practices. This interaction between commercial development and research presents the language employed in publications as an avenue for auditing for trans-inclusive language and trans-competent research design. The need for inclusiveness asks all professional communities to "think seriously and thoroughly about gender identity on its own terms" [24]. Taking gender on its own terms means considering the perspectives of those who this language describes or addresses, and even more importantly who use this language to describe themselves. Thinking of gender on its own terms involves paying attention to contemporary research that critically investigates uses of normatively gendered language, the implications such uses have, and the ideologies that underpin them. Given the overwhelming assumptions of binary and immutable conceptions of gender, we ask: how do trans, non-binary, or gender-nonconforming identities and concerns figure in the discourse of research on gender and facial recognition? As our analysis reveals, the presence of non-normative gender identities is blocked and prevented by prevailing values rather than invited into the practices of the field.

Between 2020 and 2021, we conducted searches on Summon and Google Scholar using combinations of search terms such as "gender recognition," "facial recognition," "algorithm," "software," "trans," "transgender," "non-binary," "gender," and "gender identity." From these search results, we selected those articles which discussed approaches to facial recognition that involved gender identification. We continued this search process until we reached 50 research papers published between 2010 and 2020 (see Appendix A). The authors of the articles in our corpus are affiliated with institutions in 27 countries, chief among them are the United States, China, India, Taiwan, Italy, and Pakistan (see Fig. 1 and Appendix B).

We conducted a content analysis that identified in each article sections, sentences, and phrases that 1. express

concepts of gender, 2. give voice to values for which the research strives, and 3. formulate challenges for ongoing research. These, then, are the key themes for which we coded:

1. Concepts: What phrases are used and what lexical choices are made when these research publications describe and operationalize aspects of gender and gender identity?
2. Values: What evaluative expressions do these researchers employ to promote their approach and relate it to other approaches, what do they affirm as good and best values in the field of gender and facial recognition?

   Datasets: What datasets are being used for facial and gender analysis, with what criteria in mind have they been built or selected, and how are they shown to interact with other datasets?
3. Challenges: What do these researchers present as challenges and future directions for research in gender and facial recognition?

The corpus articles were each coded by two researchers of our team, with differences in coding resolved in further discussion. In the following sections we present key findings according to the above three themes: 1. concepts, 2. values and datasets, and 3. challenges. We place our findings within the context of critical research both in trans studies and on facial and gender recognition and discuss the implications which our findings pose for trans and non-binary users. We end with recommendations for interdisciplinary work, work that appears to be urgently necessary in this research field.

2 Findings I: concepts

Concept, itself an abstract concept, is notoriously difficult to define [25]. At its most basic, a concept is a general idea for which a person forms a mental representation. However, because people bring their own beliefs and positionality to the formation of a mental representation, individual understanding necessarily varies, leading to different people having "different senses of a single…concept" [25]. Nevertheless, as "the building blocks of thoughts," concepts are fundamental to the production of knowledge [25]. Given the variability of conceptual understanding, then, it is crucial to ask who is producing knowledge and how their understanding of the concepts they bring to such knowledge production have been shaped by particular socio-cultural forces and traditions of scholarly inquiry.

Within research culture, it is a commonplace that people who belong to specific communities of scholarly inquiry (e.g., disciplines, sub-disciplines) share conceptual frameworks which have proven particularly useful to their own community's knowledge-producing activities [26]. However, as Michel Foucault pointed out long ago, this can also result in loss of, ignorance about, or devaluation of other forms of knowledge, knowledges Foucault described as "subjugated knowledges" [27]. Over the history of scholarly knowledge

Fig. 1 Locations of institutions with which authors in our corpus are affiliated (see Appendix B for full list)

production about trans people and trans lives, trans people's own knowledge about their experience has, until recently, been one such subjugated knowledge, and remains so in some contexts. Susan Stryker has therefore characterized the project of trans studies as a process of "desubjugating [these] previously marginalized forms of knowledge about gendered subjectivity and sexed embodiment" [28].

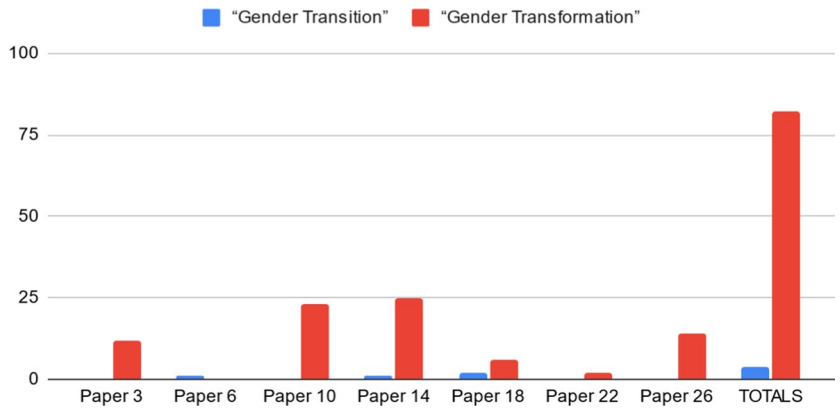
In this section of our analysis, then, we examine: how gender-related concepts in our corpus articles are reflected in the language of those articles; how the deployment of those concepts reflect the positionalities of the authors and, therefore, the socio-cultural and scholarly perspectives they represent; the degree to which these concepts and their use reveal familiarity or unfamiliarity with the perspectives of trans people, both inside and outside the academy, and therefore reflect either the ongoing subjugation or desubjugation of trans knowledges; and the potential for harm to trans and gender-diverse people and communities the language used in the deployment of these concepts represents.

While the articles in our corpus broadly focus on gender recognition, seven specifically address transgender facial recognition. The language the researchers use to characterize trans-related concepts in these seven articles suggests they are unaware of trans community language practices, or those of research disciplines like trans, gender, and queer studies. Underlying this lack of conceptual awareness, as reflected in terminology and language, is unfamiliarity with key issues that are highly relevant to trans and non-binary lives—from misconceptions about the role of medical intervention in the definition of trans identity to propositions of imagined gender deception that put trans people at risk.

2.1 Trans-exclusionary word choices and emphasis on medicalization

The seven papers in our corpus that mention trans identities almost exclusively use the term "gender transformation"—a term we have not encountered in any other English language context where trans issues are discussed—rather than the widely accepted "gender transition" [29]. Among these seven articles, only one uses the term "gender transition" over "gender transformation," and in that case mentions it only once (Paper 6, see Fig. 2). The use of the mistaken term "gender transformation" points to a lack of engagement with relevant discussion and research; we cannot emphasize enough how prevailing the term "gender transition" is in public and private discussion in English, as well as in relevant research publications ranging from sociology, literary studies, and philosophy, to psychology, psychiatry, and medicine. The use of "gender transformation" in some of the articles indicates something common to all the articles in our corpus: a deep ignorance of trans people's experiences, lives, and the dangers they face. As the following analysis makes clear, this ignorance is manifest not only in the terminological choice of "gender transformation," but also in medicalized conceptions of transness, linear and bounded conceptions of transition, and a dangerous emphasis on gender deception (also discussed in our findings on the theme of challenges).

The understanding of trans existence in these seven articles is overwhelmingly medicalized in a pathological way and conceptualized as a linear and conclusive process. There are several examples of medicalization where transition is



Paper	Author Affiliation
3	Halmstad University, Sweden
6	Hofstra University/Northwell Health, USA Microsoft Corp., USA British Hospital of Buenos Aires, Argentina
10	Norwegian University of Science and Technology, Norway International Institute of Information Technology, India *2/4 authors the same as Paper 18
14	University of North Carolina at Wilmington, USA
18	Norwegian University of Science and Technology, Norway *2/4 authors the same as Paper 10
22	Visa Inc, FM: Systems Autodesk Harvard University, USA
26	Dr. Mahalingam College of Engineering and Technology, India

Fig. 2 Counts of phrases "gender transition" and "gender transformation" in the body text of the seven papers

reduced to little more than hormone therapy. For instance, Paper 10 states that "Gender transformation is normally carried out through hormone replacement therapy (HRT) that replaces the natural sex hormone of the subject with its opposite sex." Paper 14 pronounces, "Gender transformation occurs by down selecting the natural sex hormone of a person in replacement for its opposite." And Paper 26 defines transgender people solely in relation to HRT: "A person who undergoes gender transformation via hormone replacement therapy is a transgender person."

The focus of Paper 6 differs slightly from others, using gender recognition technology to measure the "success" of facial feminization surgery (FFS). This paper is more careful to acknowledge that trans people are neither defined by medical procedures—"Facial feminization surgery is often an important *aspect* of gender confirmation" (emphasis added)—nor can one particular procedure be understood as "definitive": "For many patients, feminizing the face is an even more important step to their journey of reaching their desired gender identity than 'top' (breast augmentation) or 'bottom' (vaginoplasty) operations." Despite its more nuanced approach, this paper still strongly associates trans identity with medical procedures. This association is apparent in the above-quoted passage, where surgeries (FFS, breast augmentation, vaginoplasty) are equated with "reaching" one's identity—i.e., identity is not inherent but emerges through medical interventions. This association is also present when research results are reported: "Preoperative…images were…correctly identified as female only 58.6 percent of the time. …Postoperative…images were identified correctly 93.7 percent of the time." In this view, correct gendering is a surgical artifact.

The same paper asserts: "Facial feminization surgery results in…[an] objective improvement in gender recognition." This paper not only reinforces the idea that "successful" transitions are medical transitions, but that the success of a gender transition can be "objectively" measured by machine-learning systems which know better than human beings who is or is not a woman. Further, the researchers do not seem to have considered real-world implications, such as the pressure on trans women to conform to an AI-determined standard of "objective" womanhood and, further, that meeting such a standard demands an expensive surgical solution out of the financial reach of the majority of trans women [30] and rarely covered by health insurance providers [31, 32].

Conceptualizing gender transition as HRT or gender-affirming surgery ignores the work that trans communities have been doing in liberating our understanding of trans existence from medicalization, and the fact that increasing numbers of trans and non-binary people are choosing non-medical transitions [33]. The inability to conceive of, or acknowledge, trans existence outside of medical contexts is fundamentally dehumanizing, as is equating (even implicitly) the legitimacy of a person's gender with their ability to be recognized as such by machine-learning systems.

Related to this medicalization, a linear and teleological understanding of transition informs the work in all seven articles. First, there are only two kinds of transition mentioned: so-called male-to-female (MTF) and female-to-male (FTM). Non-binary, agender, and gender-nonconforming people largely do not exist in this body of research [34], the single exception being, in our corpus, Paper 22, discussed below. This assumption of a clear beginning point and end point is reinforced by referring to "pre-HRT" and "post-HRT," to a "before and after" of gender transition, or to "completed" transitions. Trans people, however, know that transition is rarely linear, and many experience transition as an ongoing, lifelong component of their lives—knowledge attested to in both community and research discourses [29, 35–40]. Further, unless a person chooses to stop HRT there is no such thing as "post-HRT." These articles demonstrate little knowledge of or interest in the actual complexity of trans, non-binary, and gender-nonconforming experiences, and in the important yet also problematic ways in which medical conceptions intersect with trans, non-binary, and gender-nonconforming lives.

Paper 22 departs from the other papers in that it attempts to expand facial recognition technology beyond a simple M/F binary model and in that it demonstrates somewhat more understanding of trans people's lived experiences. These researchers wish to reduce the frequency with which transgender people are misgendered by computer vision systems, recognizing that being misgendered is painful, negatively affects mental health, and can be linked to experiences of violence. To this end, they create a more gender-inclusive database and train a machine-learning system to recognize a wider range of gender possibilities. However, the expanded database draws from online pictures of known non-binary celebrities, of whom only 36% actually apply the term non-binary to themselves. The remaining 64% use a range of other gender identifiers, such as "genderqueer," "gender-fluid," and "agender" (for a total of nine, including "non-binary"). This gender classifier, then, continues to misgender any person who uses an identifier other than "non-binary." To mitigate this shortcoming, the researchers suggest their future research will model gender as a continuum between the poles of M and F as a way to be more sensitive to these intra-class non-binary variations. However, such variations do not exist on a continuum (e.g., where, between "feminine" and "masculine," does "gender-fluid" fall in relation to "genderqueer"?). Further, their proposed future research misses that non-binary identities do not simply combine aspects of, or fall between, culturally defined masculinity and femininity, but often exist outside of or beyond ideas of male and female [41–44].

Our critique of Paper 22 clarifies why, for the wider project of gender recognition, working from medicalized and linear understandings of trans and non-binary identities is problematic: these are cisnormative understandings. Trans and non-binary identities and genders are neither medical artifacts nor are they defined by medical culture. Rather, they emerge from and are defined by trans, non-binary, and gender-nonconforming people and communities, a fact that medical practitioners and researchers are increasingly recognizing [45–48]. Machine-learning systems built upon a foundation of cisnormative concepts, and the cisnormative assumptions and stereotypes those concepts reflect, can only fail in their attempts to capture the genders of people whose experience cannot be defined by or within cisnormative systems. Further, as the next section demonstrates, the unexamined cisnormativity of gender recognition research places trans people directly in harm's way.

2.2 The dubious concept of "gender deceiver"

The concept of the "gender deceiver" is, in simple terms, the "persistent stereotype of transpeople [sic] as deceivers" [49]. A common way the concept has been deployed is as a "blame-shifting discourse" which justifies or excuses violence against trans people [49]. For example, news reporting, police statements, and legal defenses have all shifted responsibility for murders of trans women away from perpetrators and onto the victims, identifying the trans women's "gender deception" as the underlying cause of the violence, a reversal which casts the victims as wrongdoers while excusing murder [49–51]. Such framing has been used even when the perpetrator already knew the person was transgender, which underscores the extent to which trans existence is often viewed as inherently deceptive. As Talia Bettcher points out, the persistence of the deceiver stereotype also perpetrates significant emotional violence against trans people through its denial of their "moral integrity and … authenticity" [49].

Similarly, technologies capable of tracking faces and bodies across gender transition deprive trans people of agency in their self-representation [52]. Given the context of violence against trans people, such technologies can constitute an existential, institutional, and societal threat for trans lives. For example, the researchers in Paper 14 in our corpus muse that a cisgender person "could self-medicate with hormone drugs to fool…face recognition systems whether for access control or to gain entry to a foreign country" and these researchers naïvely ask, "Will [a cisgender person] use HRT for the purpose of masking or creating a new identity?" In other words, the authors pose an imaginary problem that conceives of gender-affirming therapy as a threat to cisnormative operations. This imaginary problem is a variant on the claim that cisgender men could pretend to be trans to gain access to women's washrooms for the purposes of sexual assault. These imaginary problems and claims are prominently used in recent instances of US state legislation on bathroom access, legislation that is discriminatory and invites aggression and violence against trans and non-binary folk (while also not being limited to them) [53]. It is no surprise that facial recognition software has been discussed as a way to police access to bathrooms and change rooms in accordance with these laws.

Seeking a solution to such imaginary problems puts trans people at risk. There is a collapsing here of transness with deception and criminality, two enduring stereotypes mobilized for violence against trans people. Kristen Schilt and Laurel Westbrook have demonstrated the malevolence of the conception of trans people as "gender deceivers" by analyzing US media reports on homicides of those who lived a gender identity other than their birth-assigned gender [50]. Schilt and Westbrook found that a perceived failure to fulfill gender criteria was met with violent responses: nearly 95% of these homicide cases were the killing of trans women by cis men, and in a majority of instances news reporting explained this violence as "perpetrators feeling deceived by the transwomen [sic] about their 'true gender' and 'tricked' into a homosexual encounter" [50]. The enforcement of normative gender conceptions—from sexually intimate to technologically quotidian encounters—is a practice with a violent history and a violent present, particularly for trans women [54]. Current evidence indicates that technologically mediated environments amplify the hostility inherent in such enforcement [55–61]. Recent controversy over the use of facial recognition technology to control access to Giggle, a new social media platform [62], underscores how insidiously the trope of the "gender deceiver" has extended into real-world biometric applications, where it continues to harm trans women.

Schilt and Wesbrook also observe that the "gender deceiver" concept relies on an accompanying conviction that a concealed "true gender" exists beneath the trans person's visible gender presentation [50]. This "concealed truth" is most commonly associated with biological characteristics such as genitalia and chromosomes [49, 50]. Thus, this essentialist "truth" is used to override a trans person's lived experience and self-knowledge, casting such experience and knowledge as deception. The researchers in our corpus rely on the similar idea that there is an underlying gender "truth" to faces, a truth which transition cannot change or eradicate. Chosen methods of measuring facial features are explicitly advertised for being "invariant to gender transformation" (Paper 10) and settling on "gender invariant features of the face" (Paper 14) so as to measure parts of the face and determine its gender and identity no matter what changes gender transition effects. In this respect, this research regards gender as a biologically determined trait or attribute, such that identity resides not in self-conception but in that which can

be captured in government systems at birth and in photographs at any point in adult life, and which is assumed to be immutable.

This fundamentally essentialist notion is of a piece with the "gender deceiver" concept and other common positions which make appeals to the body—to birth genitals, to reproductive organs, to chromosomes—as a way to argue the illegitimacy of trans lives and claims to existence, arguments which insist that trans and non-binary people can never escape their birth-assigned gender. The desire of these facial recognition researchers to tie trans people back to their pasts through the supposed evidence of their bodies seems little different than biologically essentialist campaigns, and no less dangerous [63, 64]. The cisnormative and essentialist assumptions our analysis identifies, and the harms these assumptions perpetuate, point toward an urgent need for interdisciplinary collaboration between computer vision researchers and those who work in fields studying sociocultural aspects of gender and its effects.

3 Findings II: values and datasets

As we just discussed, the seven research articles in our corpus that do consider the existence of trans (and in one case also non-binary) people reveal deep ignorance and disregard for the reality of trans, non-binary, and gender-nonconforming lives. Diverse experiences and expressions of gender are neither valued in themselves nor for the critical questions they pose to accepted practices in facial and gender recognition research. Rather, their value is subsumed to other, already dominant values in this research discipline. The analysis in this section makes visible and addresses what these values are across the articles in our corpus. We further analyze how these values are embedded in the processes by which facial and gender recognition research is conducted and we discuss how this embedding inhibits consideration of gender other than in a cisnormative, binary way.

3.1 Performance, accuracy, and other presupposed values

Our coding reveals that the values which are explicitly expressed in our corpus cluster around a repeated set of terms. These terms are, in order of frequency: performance, accuracy, robustness, efficiency, superiority, and reliability. The values expressed through the use of these terms can be considered as self-evident within the fields of computer vision and gender recognition. However, we argue, based on our background in the study of writing and discourse, that it is often necessary to take stock of commonly used terms in order to consider how they direct research practices and interpretation of findings. The ubiquity of the terms detailed below becomes an important concern in terms of how researchers approach gender. Understanding how and how frequently key terms are used can help to unpack invisible limitations.

In our corpus, terms relating to performance and accuracy were used most consistently; they appear in every article (see Fig. 3). Among these two terms, the most frequent value is performance which is expressed in phrases such as: "improve performance of gender classification," "performance in a real-time scenario," or "best performance is achieved." Second most frequent is the value of accuracy; typical phrases that speak about accuracy are "improving search engine retrieval accuracy," "accuracy of newer databases," or "estimate age and gender attributes accurately." While the terms performance and accuracy appear in each of the papers, how often they appear is part of the choices that authors make regarding style. The element of stylistic choice is perhaps most clearly visible in one article where authors mention performance 73 times, far more than any of the other value terms is mentioned (counts of tokens are from the body of the paper and exclude use of these terms in abstracts, tables, graphs, figure captions, and reference lists).

Following accuracy and performance are terms relating to robustness, efficiency, superiority, and reliability. These value terms are used at lower frequency inside articles and do not appear consistently across all articles of the corpus. There are other terms, too, that are used repeatedly to express evaluation but that do not consistently appear across the different papers. These include objectivity, capability, practical application, extent of experiments, tolerance to distortion, or reproducibility. We can say that the most frequent value terms—like accuracy, performance, robustness, and efficiency—express the central values of the research field, with other terms assisting or promoting each paper's particular approach. The authors in our corpus usually do not take the time to explain: what is performance or accuracy in this study; on which previous discussion does the conceptualization of the term build; and how do these different terms and values relate to each other on a conceptual level?

Although there are variations in the institutional backgrounds of researchers and objectives of the research represented in the articles, the use of these terms presupposes that readers already know, share, and agree on these central values. Generally, these terms are employed in unequivocally positive ways without conditional concern. Such presupposition of value terms—with few questions, conditions, or definitions—links well to an effort of presenting algorithmic work as purely scientific research that is grounded in shared and impartial structures of knowledge. These terms express the high, unquestioned, and shared value that computer science places on measurable parameters which are often presumed to be objective. As our above discussion of the concepts of transness

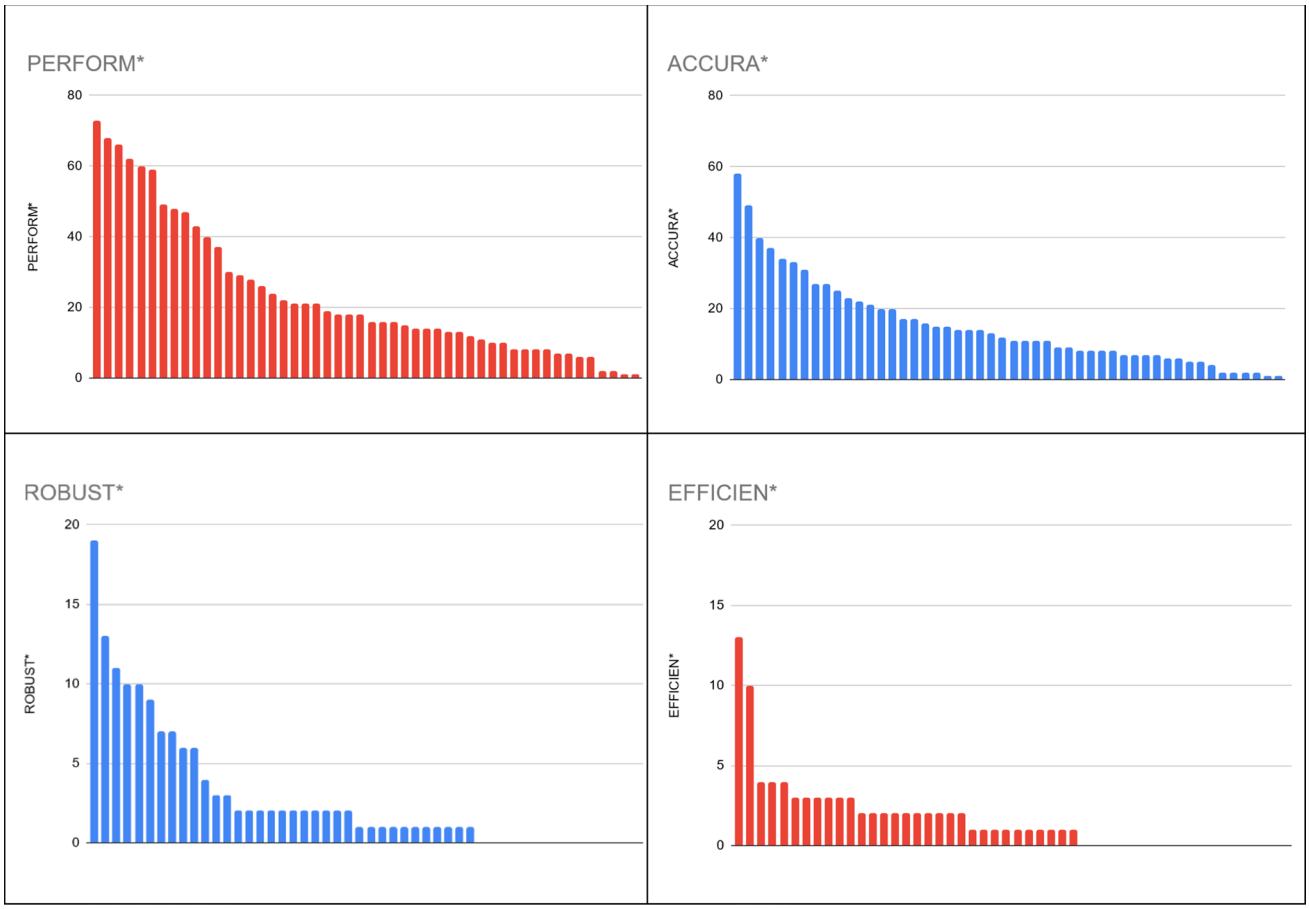


Fig. 3 Word counts of perform*, accura*, robust*, and efficien* in the body text of each of the 50 papers

and gender transition makes clear, however, gender is not a binary, immutable, or objective category. But to insist on viewing it as such serves the central and presupposed values of the field of computer vision. Methods of face analysis can be simplified to "improve the quality of final results" if gender detection is conceived as a "binary classification problem" or "binary classification task" (Paper 19; Paper 8). In the words of Paper 21, to involve binary gender in facial recognition is to "improve the efficiency of surveillance and security systems." Papers 2 and 22 note that binary gender identification acts to "reduce the search time in a large-scale database" (Paper 22).

Occasionally some of these values are weighed against each other and derive more nuanced meaning in that way. Accuracy might start to be corrupted, points out Paper 39, when "lightweight architectures" are favoured for binary gender recognition because of the savings in "processing time, memory, and storage space" that they offer. Or, "recognition accuracy" might be noted to vary depending on what and how many features are used (Paper 10). Notably, Paper 10 focuses on facial recognition of people who have undergone HRT and describes the "intra-class variations" that are the result of HRT as leading to "performance degradation of conventional face recognition systems."

In this corpus, the presupposed and unquestioning assertion of central values—like performance, accuracy, robustness, and efficiency—seems to block consideration of more than binary gender. In a similar vein, Pinar Barlas et al.'s work highlights that focus on assessing accuracy (rather than fairness) in image tagging algorithms is linked to gender stereotyping of image backgrounds as well as a tendency to read "white male" as "something more specific and bounded" than "female," "Black," or "Asian," which then rely on stereotyped backgrounds for identification [65]. Fair consideration beyond binary gender would complicate the notion of accuracy, question performance, and challenge robustness and efficiency. It would require uprooting ingrained practices and structures that support illusions of objectivity. As Kelly Gates asserts, if machines can see, "they must necessarily embody particular ways of seeing, rather than possessing a universal, disembodied, objective form of vision, outside of any particular vantage point or subject position" [66]. Making visible the values which current terminology embeds in research on gender recognition

must be viewed as integral to the work of facial recognition researchers and technologists as they reconsider current and develop future research and design. Taken together, our findings relating to concepts of gender and terms of valuation thus suggest that—regarding ethics in computer vision—it is highly necessary for researchers and practitioners to engage in ongoing and critical examination of both the gender concepts and prominent values that are embedded in the field.

3.2 Values embedded in datasets

Shared datasets have also acquired central importance in the assessment of performance, accuracy, efficiency, and reliability. Work with a single or custom-made database might be criticized for not reflecting the complexity of real world conditions. The reuse of datasets across different projects enables assertions about increased performance or accuracy and thereby gives direction to claims about how research moves forward by mastering new challenges. By that dynamic, the problems highlighted in our project are, as illustrated above, mostly out of sight from these researchers' ways of looking. Within computer vision research, much effort has gone towards benchmarking one's approach across different datasets: it is how the gaze of computer vision researchers has been trained. As Paper 2 in our corpus claims, "objective comparison between different gender recognition approaches" becomes possible when published work is based on replicable datasets. Paper 3 is a review paper which lists the most used databases for periocular analysis "so each new work builds on top of previous work" in order to produce "additional improvements" and "bring accuracy to even better levels." When developing a new approach to gender recognition, like Paper 7 does, popular datasets may be used to show how that approach is superior to others which have used the same datasets by demonstrating "significant performance improvement in terms of accuracy and efficiency."

While a range of datasets are used in our international corpus of 50 articles, there is also a clustering around large datasets that are repeatedly shared and prominently employed for benchmarking practices. In our corpus, these are the following databases: Labeled Faces in the Wild (in 14/50 papers), FERET (in 13/50 papers), Adience (in 12/50 papers), MORPH (in 8/50 papers), and University of Notre Dame collections (in 7/50 papers). Two of the papers in our corpus reviewed existing techniques and datasets and so did not do their own facial or gender recognition testing. Of the other 48 papers, 19 collected their own images and thus built their own datasets, some by interacting with research participants and others by scraping images from public Flickr albums, YouTube videos, or celebrity photo sites. In 11 of these 19 cases, the face or gender recognition approach trained on the project-specific datasets is also assessed against other, shared datasets. Overall, our corpus shows the balance leaning strongly toward multiple datasets being employed in the research. Of the 48 papers which included testing of facial and gender recognition approaches, 17 papers worked with only one type of dataset. They were outnumbered by the 16 papers in which 2 datasets were used, 8 papers in which 3 datasets were used, 4 papers in which 4 datasets were used, and 3 papers in which 5 datasets were used.

Clearly, the use of several datasets and comparisons across them serve the aims of greater performance and accuracy, which we demonstrated to be the key values expressed in these papers. However, this practice raises questions of research ethics in more than one way. First, the collection and wide sharing of these datasets happens without sufficient or informed consent from the subjects whose images are being used and reused, and whose personal and bodily characteristics are being continually measured, assessed, and categorized [5, 7, 67]. In this research field, it has become standard to collect thousands, sometimes even millions, of images without consent and for unexplained purposes, sometimes including images from intimate settings, with partial nudity, and of children. According to Abeba Birhane and Vinay Uday Prabhu, the development of computer vision suffers from a culture where "the appropriation of images of real people as raw material free for the taking has come to be perceived as the norm" [67]. Given current possibilities of reverse image search along with the printing of sample photos inside research papers, claims about anonymization of those images are "both ephemeral and vacuous" [67]. Second, the continued reliance on categories according to which a previous dataset has been structured calcifies the binary and immutable conception of gender that was embedded decades and years earlier. The design and content of datasets defines "what computers can be programmed to 'see'" [66]. Audits of computer vision software can heighten this effect: while auditing practices make producers more adherent to the given process (thereby promising to increase performance and accuracy of their product), they also tend to entrench binary gender categories [68]. When accuracy of gender recognition is partially defined by the categories which a small number of past computer scientists set—while actively ignoring how people live, define, and present their gender—the concept of accuracy will easily serve oppressive social, political, and religious structures and their reductive notions of our gendered lives.

Such serious lapses in research ethics result in harm to minoritized groups and further aid "the gradual erosion of privacy, consent, and agency of both the individual and the collective" [67]. Writing about the history of gender as a concept in databases and computer systems, Mar Hicks has documented how early computerized databases and systems "reified binary gender and strengthened the fiction of gender as an unchanged and unchanging category"

despite the flexibility that their programming allowed [69]. In Hicks' study, these databases are part of the 1962 computerized system that the British government developed to collect taxes and disburse state pensions. From its inception, trans people were programmed out of the system, their existence turned into "exception cases" that required workarounds, manual oversight, and special approval from higher administrative levels. Such programming choices create ongoing friction for trans, non-binary, and gender-nonconforming people interacting with the system, raising the likelihood that for them "benefits would either be denied, delayed, or made harder to access" [69]. In a system that is biased against trans, non-binary, and gender-nonconforming people, they are turned into challenges, exceptions, suspects, and deviants that "have to be dealt with as being aberrant from the norm" [69]. The creation of computerized systems and databases that treat trans people as exceptions is clear algorithmic bias.

Analyzing databases used by ten commercial providers of computer vision services, Morgan Klaus Scheuerman, Jacob Paul, and Jed Brubaker show how contemporary facial analysis technology "merges the social and technical identities of individuals" through their physical appearance into a "new algorithmic identity" [21]. They correctly point out that "calcifying social identities into fixed, technical infrastructures" is a key effect of this algorithmic work [21]. Among the ten services they analyzed, one did not provide gender classification and all others defined gender as only binary with never more than two categories, usually male/female. This calcified binary contrasts strongly with the range of gender terms the authors found associated, via hashtags, in a sample of nearly 2500 public Instagram photos they also analyzed. The most prominent gender-themed hashtags were: agender, female, femme, genderqueer, male, man, non-binary, trans, transgender, and woman. While the field of facial recognition research moves forward by including more and more challenging images (see next section), it continues to look back to previous uses of datasets to assert increased performance or superior accuracy in comparison. From the moment when these datasets were first used, the calculation of performance and accuracy has depended on slotting faces into one of two categories, male or female, and on slotting one person's image repeatedly into the same category no matter what else changes. Our analysis of values and datasets demonstrates how they ingrain and calcify immutable and binary understandings of gender, overwriting nuanced gender categories and lived experience, and permanently relegating gender-diverse people to the status of exceptions and deviations. As with our analysis of concepts, these findings demonstrate a similar need for interdisciplinary consultation and collaboration.

4 Findings III: challenges

In our above discussion on how gender is conceptualized, how values are expressed, and how datasets are used in our corpus, we have addressed aspects of how gender and facial recognition research is set up and how its findings are evaluated. For this section, we coded for the theme of challenges. Given the complex scope and ethical concerns of the tasks that facial and gender recognition sets itself, what do researchers conceive of as the important issues to consider in further research on gender recognition technology? We have grouped the discussion of these challenges into the following categories: challenges in datasets and image acquisition, challenges posed by gender transition, and challenges for future technological development. We note that in the papers in our corpus there is an absence of challenges related to research ethics and challenges arising from ethical problems presented in analyses of the history of computer vision.

4.1 Challenges in image acquisition and datasets

In relation to available datasets and the process of image acquisition, mentioned challenges are image collection and the state of the bodies and faces captured. These challenges include "noise in the images" (Paper 1), "occluded and badly illuminated faces" (Paper 2), and the "variation of parameters such as illumination, pose, resolution, size, and background" (Paper 29). In relation to gender, this also includes hair styles, ornamentation, and clothing (Paper 23). Images gathered through more controlled conditions, with stable lighting and bodies, are understood to be more reliable and lead to "faster and more accurate" estimations (Paper 8), values shown to be centrally important throughout the corpus. However, articles in our corpus also boost the significance of their research by embracing "even more challenging conditions which limit the robustness of the existing face recognition systems" (Paper 8). Testing the technology on datasets that represent "real-world images" (Paper 8) or what are termed "uncontrolled" (Paper 11), "in the wild" (Paper 4), "wild face images" (Paper 23) can include physical movement, facial expressions, and changes to the face due to medical aspects of gender transition.

The challenges identified when capturing the complex, dynamic, and fluid aspects of gender in facial recognition are similar challenges (with the same underlying concepts and values) as expressed in research and commercial applications in animal biometrics. For example, research on the identification and tracking of individual salmon and cattle is focused on how to identify distinguishing features

of "faces in the wild" (in all their variations), and how to accurately and quickly link those features to binaries of sex and gender. In the application of facial recognition to animal biometrics, correct sex identification is understood as necessary for breeding, and accurate individuation is understood as necessary for tracking health and ownership as well as building a medical and genetic history. In the case of cattle, this includes ensuring that a cow's genetic background and history can be verified from birth to slaughter [70]. Discussion of challenges with the use of images in human biometric identification can carry similar imperatives as animal and even plant biometrics [71, 72], including biological sex identification and accurate individuation. While articles in our corpus do not link their interest in sex identification and facial individuation to sexual, racial, or criminal typology—as pseudo-scientific approaches do [73–76]—our above discussion of datasets has highlighted that such individuation happens within the classificatory structure of datasets. And those classificatory structures continue to be beholden to limited and often biological concepts of sex that are shared with animal biometrics.

4.2 Gender transition as image challenge

The challenge of gender transition is often expressed as an intensification of the challenges already identified in image acquisition—as Paper 10 describes it, "Gender transformation presents even more challenging conditions which limits the robustness of the existing face recognition systems." Gender transition is also linked to the threat of those who evade detection and categorization by facial recognition technology, which includes "faces under plastic surgery, disguise, threeD masks for spoofing, and gender transformation" (Paper 14). In Paper 22, image capture and classification of gender are impacted by cultural and social signs of gender that are presented as a problem of masking: "classification accuracy is also affected by different masks on face. For example, we noticed that people who are wearing glasses, or heavy makeups are more likely to be misclassified." Although Paper 14 acknowledges that people undergoing HRT and surgery are not deliberately engaging in "biometric obfuscation," they still apply general suspicion to trans faces and bodies: "will someone use HRT for the purpose of masking or creating a new identity?" In response, the approach focuses on biological sex, favouring it over gender identity by seeking to isolate biological sex in particular physical characteristics, such as the ear:

> the ear can be easily captured from a distance without full cooperation of subjects…the ear has rich and stable structure which remains unchanged from 8 to 70 years of age. In addition to, it is not affected by changes in facial expressions, the use of cosmetics or psychological factors. (Paper 31)
>
> This research links to animal biometrics in its reduction of human subjects to biological and physiological signifiers of sex that can be captured and interpreted by the researcher and subsequently the technology "without full cooperation of subjects" (Paper 31).

When trans identities are considered, gender transition—or as Paper 10 puts it, "the gender transformation (or transgender) problem"—is positioned as a new opportunity for facial biometrics. Trans faces are presented as posing a challenge to the robustness of these systems, a chance to improve the technology in relation to ever more complex situations and conditions: "we focus on gender recognition as a useful tool to improve the performances of active digital signage" (Paper 32). Interestingly, we have found that the research connects the limitations of computer vision systems to social contexts within which gender is expressed. Paper 1 claims, "Gender classification is undoubtedly a simple task for humans, however, it is still an active research problem that draws the attention of many researchers in various fields." Unlike humans, these systems are unable to conceive of gender with the help of social cues, interactive practices, and complex narratives. However, this limit to their capabilities is framed in terms of the system's potential to exceed a human ability to "classify" faces according to their "correct" gender as tied to biological sex (Paper 12). Research in computer vision perpetuates, in Gates' words, "the assumption that biometrics are derived from and link directly to physical bodies," thereby concealing the complex technological mediations that are, in fact, the core work of the field [66].

Lack of accuracy in classifying gender is tied to the challenge posed by those who might deliberately manipulate these limitations. For example, in regard to facial recognition and cell phone technology, the improvement of gender estimation systems is directly linked to protections from gender "imposters" who seek to victimize users (Paper 9). The possibilities posed by gender identification in relation to gender transition include real world applications in medical contexts, corrective surgery, and robotics (Paper 11; Paper 4). As we have shown, imperatives of binary biological sex are historically embedded through the use of datasets and are perpetuated through contemporary emphasis on performance and accuracy. Even when, in encounters with trans faces, they appear as challenges to gender recognition approaches, they tend not to be questioned and are instead affirmed. So far, this research does not take on the challenge of more fundamentally interrogating those imperatives, even as research in other fields—notably gender, trans, and queer studies—is studying extensively how gender is lived and experienced and is developing more sophisticated ways of thinking about gender.

5 Conclusion

Our analysis confirms critical questions that trans people have repeatedly voiced in relation to facial and gender recognition technology. Looking closely at 50 international research papers published between 2010 and 2020, we found an overwhelming reliance on a binary and immutable conception of gender as well as a deep absence of knowledge about how technological choices in gender recognition affect trans, non-binary, and gender-nonconforming lives. This absence of knowledge manifests itself even in the seven articles in our corpus that do consider trans, and in one case also non-binary, faces and bodies. In the other 43 articles of the corpus the possibility of trans and non-binary existence is entirely omitted. In the seven articles that mention trans identity, lack of knowledge appears in the form of misapprehending processes and experiences of gender transition, emphasizing medicalization in relationship to trans identity, and employing the concept of "gender deceiver" while posing trans and non-binary faces as a deviation from cisnormative practice. We point out how dangerous these conceptions are for trans and non-binary lives.

Attentiveness to gendered experience is not a stated value in the research papers we analyzed. Rather, the central values are exclusively related to technical aspects: the performance, accuracy, robustness, efficiency, superiority, and reliability of the different ways to algorithmically determine gender. While the words that express these values are repeatedly used, these values are not explained, explored, or questioned as concepts central to the research. Scholarship in the 50 papers on gender and facial recognition represented in this study continues to hold up these technical values in a way that tends to block consideration of trans, non-binary, and gender-nonconforming experience in relationship to the gender recognition approaches that are being discussed. This relationship is embedded in the use and re-use of shared datasets—which contain only binary and immutable gender categories—and which have become key in assertions about increased performance, accuracy, robustness, and efficiency. The conception of gender as binary and immutable runs deep in this research. Current trends, such as benchmarking with shared datasets, further calcify this conception. Although we recognize the limits of our research in the number of articles analyzed, our findings confirm a critical concern that when presenting trans faces as challenges for facial recognition research, the research discussion in gender and facial recognition scholarship represented here falls back on forms of biological essentialism. Gender identity outside the cisgender norm is viewed in terms of "faces in the wild" where the aim is to identify an underlying and unchanging biometric identity regardless of outward appearance.

We conducted this project as a way of speaking against prevailing practices in computer science and engineering. Research in machine learning and artificial intelligence does indeed value interdisciplinary work, and often calls for more of it. But which disciplines are taken on board and which research from relevant fields is listened to? In the case of facial and gender recognition, fields such as gender, queer, and trans studies are areas of research which should obviously be included in the discussion and development of all facial and gender recognition techniques. And yet, there are almost no references to these areas of research. How can researchers in computer vision be made aware, in their daily work, that algorithmic decisions are not neutral and that instead they need to develop ways to interact with experiential and researched perspectives that can demonstrate what negative effects their work has? Considering the scope of our own data set we call for further research and critical practice that can address the conception of gender as a binary, a conception which is overwhelmingly reflected in the language—and thereby in the thinking—of the facial and gender recognition researchers in our corpus.

There is a serious lack of understanding in gender recognition research about what is going on in the world of gendered experience as well as in qualitative research on it. This lack of understanding has ethical implications that are in urgent need of researchers' attention. Guidelines for ethical considerations must be improved, and processes of review and peer review need to become more critical of not only how gender is conceptualized in this research but also how the proposed approaches take trans and non-binary people's lived experience and technological interactions into account. The ethical effects of this research reach far beyond particular findings of individual studies. In the form of datasets and binary operations, they are embedded in some of the key tools of the field, and through commercial and governmental applications their effects touch all aspects of public and private life. Two recommendations arise from our analysis: First, researchers in the field of computer vision must work in interdisciplinary ways with researchers who have been studying gender as a socio-cultural phenomenon. Second, journal editors and conference organizers should take a similar interdisciplinary approach where peer review and conference acceptance are concerned. In short, our project highlights a stark need for more and different interdisciplinary work in the field of computer vision so the field can develop a more sophisticated understanding of gender. Especially in the way that this work affects trans and non-binary populations, it must take trans and non-binary perspectives into account.

Appendix A: Journal titles

Sum of articles per journal	Journal titles for all 50 corpus articles
7	Pattern Recognition Letters (Elsevier)
3	Neurocomputing (Elsevier)
2	Applied Sciences (MDPI)
2	IEEE Transactions on Information Forensics and Security
2	Journal of Ambient Intelligence and Humanized Computing (Springer)
2	Sensors (MDPI)
1	ACM Conference on Web Science
1	arXiv
1	Clinical Anatomy (Wiley)
1	Computer Vision and Image Understanding (Elsevier)
1	Electronics (MDPI)
1	EURASIP Journal on Image and Video Processing (Springer)
1	European Journal of Science and Technology
1	IEEE Conference on Advanced Video and Signal Based Surveillance
1	IEEE International Conference on Identity, Security and Behavior Analysis
1	IEEE International Conference on Multimedia and Expo Workshops
1	IEEE International Seminar on Research of Information Technology and Intelligent Systems
1	IEEE International Joint Symposium on Artificial Intelligence and Natural Language Processing
1	IEEE International Workshop on Biometrics and Forensics
1	IEEE Students Conference on Engineering and Systems
1	IEEE Transactions on Pattern Analysis and Machine Intelligence
1	IEEE Workshop on Applications of Computer Vision
1	IET Computer Vision (Wiley)
1	International Conference on Biometrics
1	International Conference on Computers, Communications, and Systems
1	International Conference on Information and Communication Technology
1	International Conference on Intelligent Informatics and Biomedical Sciences
1	International Journal of Advanced Robotic Systems (SAGE)
1	Intl. Seminar on Research of Information Technology & Intelligence Systems
1	Journal of Real-Time Image Processing (Springer)
1	Journal of Visual Communication and Image Representation (Elsevier)
1	Machine Visions and Applications (Springer)
1	Multimedia Tools and Applications (Springer)
1	Plastic and Reconstructive Surgery (Am Soc of Plastic Surgeons)
1	Proceedings of the Federated Conf. on Computer Science & Information Systems
1	Procedia Computer Science (Elsevier)
1	Procedia Technology (Elsevier)
1	Symmetry (MDPI)

Appendix B: Author affiliations

Country	Affiliations for all authors	Sum
USA	Cleveland State University, USA	12
	Florida Institute of Technology, USA	
	Massachusetts University of Technology, USA	
	Microsoft Corporation	
	University of Dayton, USA	
	University of Miami, USA × 2	
	University of North Carolina at Wilmington, USA	
	University of Notre Dame, USA	
	Visa Inc. × 2	
	Zucker School of Medicine at Hofstra/Northwell	

Country	Affiliations for all authors	Sum
China	Hunan University, China	8
	National Supercomputing Center, China	
	Harbin Institute of Technology, China	
	Shenzhen Sunwin Intelligent Corporation, China	
	Nanchang University, China	
	Huazhong University of Science and Technology, China	
	Shanghai Institute of Technology, China	
	National University of Defence Technology, China	
India	Ambedkar Institute of Technology, India	8
	GJ University of Science & Technology, India	
	Indian Institute of Technology, India	
	Institute of Technology, India	
	International Institute of Information Technology, India	
	Dr. Mahalingam College of Engineering and Technology, India	
	Mepco Schlenk Engineering College, India	
	Indian Institute of Technology Indore, India	
Taiwan	National Chin-Yi University of Technology, Taiwan × 2	8
	National Taichung University of Science and Technology, Taiwan × 2	
	National Chung Hsing University, Taiwan	
	National Central University, Taiwan	
	National United University, Taiwan	
	Asia University, Taiwan	
Italy	Centro Studi Srl, Italy	7
	National Research Council of Italy, Italy × 2	
	University of Catania, Italy	
	University of Florence, Italy	
	University of Milano-Bicocca, Italy	
	University of Salerno, Italy	
Pakistan	Bahria University, Pakistan	7
	Institute of Information Technology, Pakistan	
	National Textile University, Pakistan	
	Shaheed Benazir Bhutto Women University, Pakistan	
	University Faisalabad, Pakistan	
	University of Azad Jammu and Kashmir, Pakistan	
	University of Engineering and Technology, Pakistan	
Spain	Universidad de Málaga, Spain	5
	Universidad Politécnica de Madrid, Spain	
	Universidad Rey Juan Carlos, Spain	
	Universitat Autonoma de Barcelona, Spain	
	University of Salamanca, Spain	
South Korea	Dankook University, South Korea	4
	Namseaul University, South Korea	
	Sejong University, South Korea	
	Yonsei University, South Korea	
Norway	Norwegian University of Science and Technology, Norway × 2	3
	Philips Research, Norway	
Saudi Arabia	King Abdulaziz City for Science and Technology, Saudi Arabia	3
	King Saud University, Saudi Arabia	
	Saudi Information Technology Company, Saudi Arabia	
Israel	Adience Inc., Israel	2
	Open University of Israel	
Turkey	Firat University, Turkey	2
	Istanbul Technical University, Turkey	
UK	University of Bristol, UK	2
	University of Portsmouth, UK	
Argentina	British Hospital of Buenos Aires	1
Canada	York University, Canada	1
Chile	Universidad Católica del Norte, Chile	1
Egypt	Assiut University, Egypt	1
Finland	University of Tampere, Finland	1
Indonesia	Telkom University, Indonesia	1
Japan	Tokyo Metropolitan University, Japan	1
Poland	AGH University of Science and Technology, Poland	1

Country	Affiliations for all authors	Sum
Portugal	University of Beira Interior, Portugal	1
Singapore	Nanyang Technological University, Singapore	1
Sweden	Halmstad University, Sweden	1
Switzerland	Lastminute Group, Switzerland	1
Thailand	Mahasarakham University, Thailand	1
Vietnam	Ho Chi Minh City Open University, Vietnam	1

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Declarations

Conflict of interest The authors have no conflicts of interest to declare, neither financial nor otherwise.

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