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Intersectional HCI on a Budget: An Analytical Approach Powered by Types

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ABSTRACT

Intersectional HCI recognizes that humans' interconnected social identities shape their experiences with technology. However, intersectional HCI requires extensive resources, such as access to intersectional populations, which many HCI practitioners may lack. For these practitioners, we present an analytical approach to bring intersectional lenses to HCI practices. The approach uses types—not at the level of identities, but at the level of personal traits drawn from foundational research. We first formally prove that certain analytical methods for detecting inclusivity issues can be meaningfully composed to provide equitable consideration of typically overlooked populations; then present four design use-cases to illustrate what the approach brings to HCI practices; and then empirically investigated one of the four use-cases with 24 HCI participants. Results show that practitioners using the compositional approach detected even more intersectional inclusivity problems than those using a complementary intersectional approach.

KEYWORDS

Intersectional HCI; analytical design methods; InclusiveMag; types

CCS CONCEPT

Human-centered computing → Human-computer interaction (HCI); HCI design and evaluation methods

1. Introduction

Practices in HCI have recently been shifting from designing for supposedly homogeneous "users," towards more informed and/or disaggregated practices that recognize users' various and overlapping identities. However, as a meta-review by Schlesinger et al. (2017) points out, most of the literature considers only one identity dimension, such as gender or socioeconomic status (SES).

Such one-dimensional approaches have been important and impactful (Prana et al., 2022), but they have not been able to serve people with certain combinations of multiple, intersecting identities (Erete et al., 2020; Rankin & Irish, 2020; Winchester et al., 2022). A well-known example is the face recognition failure rate for Black women, in which facial recognition systems achieved reasonable accuracy when predicting for men and for women and for people with both darker and lighter skins—but these one-dimensional evaluations did not reveal the huge lack of support for darker-skinned women (Buolamwini, 2017; Buolamwini & Gebru, 2018).

Intersectional HCI researchers have been working to fill this one-dimensional research gap. Their empirical investigations have been uncovering in-depth information, both qualitative and quantitative (Bowleg, 2008; Erete et al., 2020), about individuals' everyday experiences at the intersection of identities such as gender, race, and class, as well as about challenges that technology introduces for individuals in these intersections (Rankin et al., 2021).

However, not every HCI practitioner, such as some in practical industrial positions, has the resources or expertise to engage in the kind of in-depth work these intersectionality researchers are able to do. One reason is that in-depth intersectionality work relies heavily on empirical work with actual members of the population of interest (Booth et al., 2018; Costello, 2012; Rankin et al., 2021; Tuli et al., 2019), which leads to the challenge of gaining access to and the willingness of "enough" members of that particular population to participate. Even after gaining access, members may still be marginalized if the HCI practitioner lacks the expertise to bring reflexive measures to improve explicit consideration of intersectional identities (Boyd, 2023; Smyth & Dimond, 2014).

This paper aims to enable HCI practitioners who are not in a position to do full-scale intersectionality work to bring at least some of the benefits of intersectional HCI to the technologies they are designing. Toward that end, we present a new "discount" approach (Nielsen, 1989) to design with intersectional awareness. The approach does not aim to produce foundational intersectionality results, and is not empirical. Rather, it harvests empirical and theoretical foundations laid by prior experts and combines them into an analytical method that can handle a user's multiple identities.

Analytical methods, [1] such as heuristic evaluation (Nielsen & Molich, 1990) and cognitive walkthroughs (Mahatody et al., 2010; Wharton et al., 1994), have contributed extensively to

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HCI. Some practitioners use analytical methods because they do not have the time or resources to do more (Hollingsed & Novick, 2007). Other practitioners use analytical methods before and/or in addition to empirical work with flesh-and-blood users (Interaction Design Foundation, 2016) to catch and fix some design problems early in the design cycle when fixing problems is easier than fixing them later in the cycle. Recently, to bring such benefits to intersectional HCI, intersectionality researchers have begun to advocate for new analytical methods. For example, Bowleg (2008) advocates considering structural inequities analytically—one dimension at a time first (e.g., first gender alone, then race alone), as a preliminary step, and then moving on to considering such inequities analytically for intersectional identities (e.g., Black women, Black men, …). Boyd et al. (2022) and Smyth and Dimond (2014) have contributed intersectional analytical frameworks to allow decision-makers to analytically find biases in both the technologies they create and in the environments in which they design the technologies.

The analytical approach we present here builds upon this history of analytical methods. The approach enables composing prior work from applicable "diversity dimensions" to consider ranges of personal traits that individuals in all the intersections of those diversity dimensions might have. For example, it enables composing prior work on socioeconomically diverse users' ranges of personal traits (first diversity dimension: SES) with prior work on age-diverse users' ranges of traits (second diversity dimension: age) in a way that considers all intersections of those two dimensions: namely, high-SES young adults, high-SES elderly adults, low-SES young adults, and low-SES elderly adults. This approach is a discount method in that it enables harvesting other researchers' prior work, instead of requiring HCI practitioners to do foundational empirical work into an intersectional population if they lack the expertise to do so.

Behind the approach is a compositional model. The model does *not* compose at the level of a person's identities—it instead composes at the level of a multiple-value spectrum of personal traits. We term such spectra of personal traits *facet types*. A facet type captures an entire spectrum of *facet values* of particular relevance to user experiences with technology, such as a spectrum of attitudes toward taking risks with technology (from welcoming risks in technology to avoiding them, and every value between), a spectrum of perceived self-efficacy levels, a spectrum of literacy levels, etc. Our approach does not choose these facet types—it instead reuses facet types that other inclusivity researchers have previously shown to have particular impacts on how people of certain identities experience technologies. For example, prior research has shown that some values of the facet type "attitude toward (tech) risk" are disproportionately common for some gender identities (Anderson et al., 2024; Burnett, Stumpf, et al., 2016); likewise for some socioeconomic identities (Burnett et al., 2024).

Facet types are, of course, types, which suggests borrowing some notions of types from programming language theory (Pierce, 2002). In one interpretation, a *type* stands for *all possible values* of that type; for example, type Integer stands for *every* possible integer value, not just a generalization based on a sample. Applying this to the risk facet example, the facet type "attitude toward risks with tech" stands for every possible attitude toward risk.

Thus in this paper, we show how an HCI practitioner can leverage the power of types—here, facet types—to compose or decompose existing analytical methods in the InclusiveMag family of analytical methods (Mendez et al., 2019), to produce new analytical methods for an intersectional population. For example, HCI practitioners could use the approach to consider intersectional groups like low-SES elderly women and high-SES young men, by systematically combining prior research on age, on gender, and on socioeconomic status. Our contributions are:

- An *analytical* approach enabling HCI practitioners to reason about intersectional populations at the level of facet types that affect usability, instead of individual values of identity.
- A *compositional model* of facet types enabling diversity dimensions to be joined and split while preserving their analytical properties (Section 4).
- A *formal evaluation* in the form of a formal proof of the model's correctness (Section 4.2).
- Several *practical usage scenarios* for HCI practitioners in a variety of HCI design use-cases (Section 5).
- An *empirical case study* of how the approach fared in practice when used by 24 HCI researchers and practitioners (Section 6).

1.1. Researcher self-disclosure

Our research team has diverse and intersecting identities. We identify as different genders and hold different citizenships and different immigration statuses. We come from different and intersecting races (Asian, Black, and White) and ethnicities (South Asian, East Asian, Middle Eastern, African, and North American). Our lived experiences motivate us to propose this approach to intersectional HCI, by which we hope to enable even practitioners who think they cannot "afford" intersectional HCI to create more inclusive technology than they otherwise would.

2. Background

Reasoning at the level of types requires analytical methods that are consistent with the notion of types as sets of values. One family of methods that fulfills this requirement, and the one we chose to use, is the *InclusiveMag* family.

InclusiveMag (Mendez et al., 2019) is a meta-method that enables HCI researchers to generate systematic analytical design methods for a given diversity dimension (Figure 1). The generated methods are framed with *facet types* and *facet values*. Designers and other software practitioners can then use an InclusiveMag-generated method to analytically evaluate user experiences from the perspective of users across the given diversity dimension.

For example, InclusiveMag was used to generate GenderMag, a systematic analytical method for the diversity dimension of gender (Burnett, Stumpf, et al., 2016; Mendez et al., 2019).[2] HCI practitioners have used the GenderMag method to find, avoid, and fix inclusivity issues in a variety of domains, such as education software (Burnett, Stumpf, et al., 2016; Cunningham et al., 2016; Hilderbrand et al., 2020; Shekhar & Marsden, 2018), machine learning aids (Burnett, Peters, et al., 2016), office productivity software (Hill et al., 2017), open source project sites (Chatterjee et al., 2021; Ford et al., 2019; Padala et al., 2022), robotics (Balali et al., 2019; Fallatah, 2023; Showkat & Grimm, 2018), software tools (Gralha et al., 2019), and search interfaces (Vorvoreanu et al., 2019). Other offspring of InclusiveMag include SESMag to support users in diverse socioeconomic situations (Burnett et al., 2024), AgeMag to evaluate age bias in e-commerce applications (McIntosh et al., 2021), and a collection of eight pilot InclusiveMag-generated methods to support eight diversity dimensions (e.g., eyesight, attention span, position along the autism spectrum) (Mendez et al., 2019).

Figure 1 shows InclusiveMag's three steps: Scope, Derive, and Apply. The first step, Scope, produces a set of facet types for the *diversity dimension* of interest (e.g., gender, in the GenderMag example). These *facet types* represent traits for which individuals at opposite ends of the diversity dimension can differ significantly from each other.

In InclusiveMag's second step, Derive, inclusivity researchers use the facet types they created in the Scope step to derive mechanisms for HCI/software practitioners to use when designing/evaluating a system's inclusivity, such as Figure 2's personas. For example, the GenderMag personas in Figure 2 enumerate GenderMag's five facet types and some of the possible facet values different individuals might have. The researchers also specialize an existing analytic method, such as a cognitive walkthrough or set of design heuristics, using the facet types. This paper uses such a cognitive walkthrough with facet types and facet values for type-based reasoning.

Finally, in the third step, Apply, HCI/software practitioners customize and apply the generated method(s) or other facet-based artifacts (e.g., personas) to evaluate/redesign their technology to increase its inclusivity across that diversity dimension. For example, if in the Derive step the HCI researchers chose to specialize in a cognitive walkthrough for the analytic process, then in the Apply step the practitioners can conduct this specialized cognitive walkthrough. This paper shows how for the Apply step, these practitioners can compose one or more of these methods and/or sets of facet types to evaluate/redesign their technology to be more inclusive across multiple diversity dimensions.

3. Related work

Intersectionality is a critical social theory that explains how the interconnected nature of social constructs and identities such as gender, sexuality, race, and class create an overlapping system of privilege and oppression (Andalibi et al., 2022; Bowleg, 2008; Crenshaw, 1991). The central ideas of intersectionality have long historical roots that date back to the 19th century when Black women, Chicanos, Native American women, Afro-Brazilian women, and other women of color fought for their civil and human rights (Hill Collins, 2002, 2019; Rankin & Owensby Thomas, 2020). Abolitionist and women's rights activist Sojourner Truth, Latina, post-colonial, queer, and Indigenous scholars all have also produced work that describes their everyday experiences at the intersection of their social identities (Andalibi et al., 2022; Bowleg & Bauer, 2016; Bunjun, 2010; Hill Collins, 2002; Hankivsky, 2022; Valdes, 1997; Herk et al., 2011). Later, Kimberlé Crenshaw illustrated the importance of intersectionality in the DeGraffenreid v. General Motors lawsuit, where five Black women alleged that General Motors' "last-hired, first-fired" lay-off policy was discriminatory (Crenshaw, 1991; District Judge, 1976). However, the Court's research failed to identify such discrimination because General Motors had hired White women and Black men, and neglected the combined race and gender discrimination that Black women experience. Since then, the term intersectionality has been used in various fields, including Information Technology and HCI, to advocate social justice

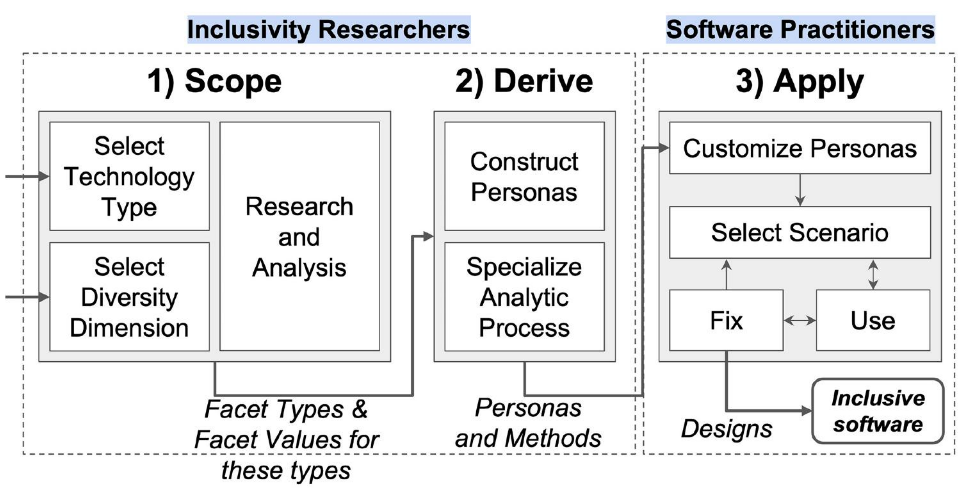


Figure 1. The InclusiveMag meta-method has three steps. The first step outputs facet types and the range of possible values that each facet type can have. These facet types provide the starting point for the type-based reasoning we present in this paper.

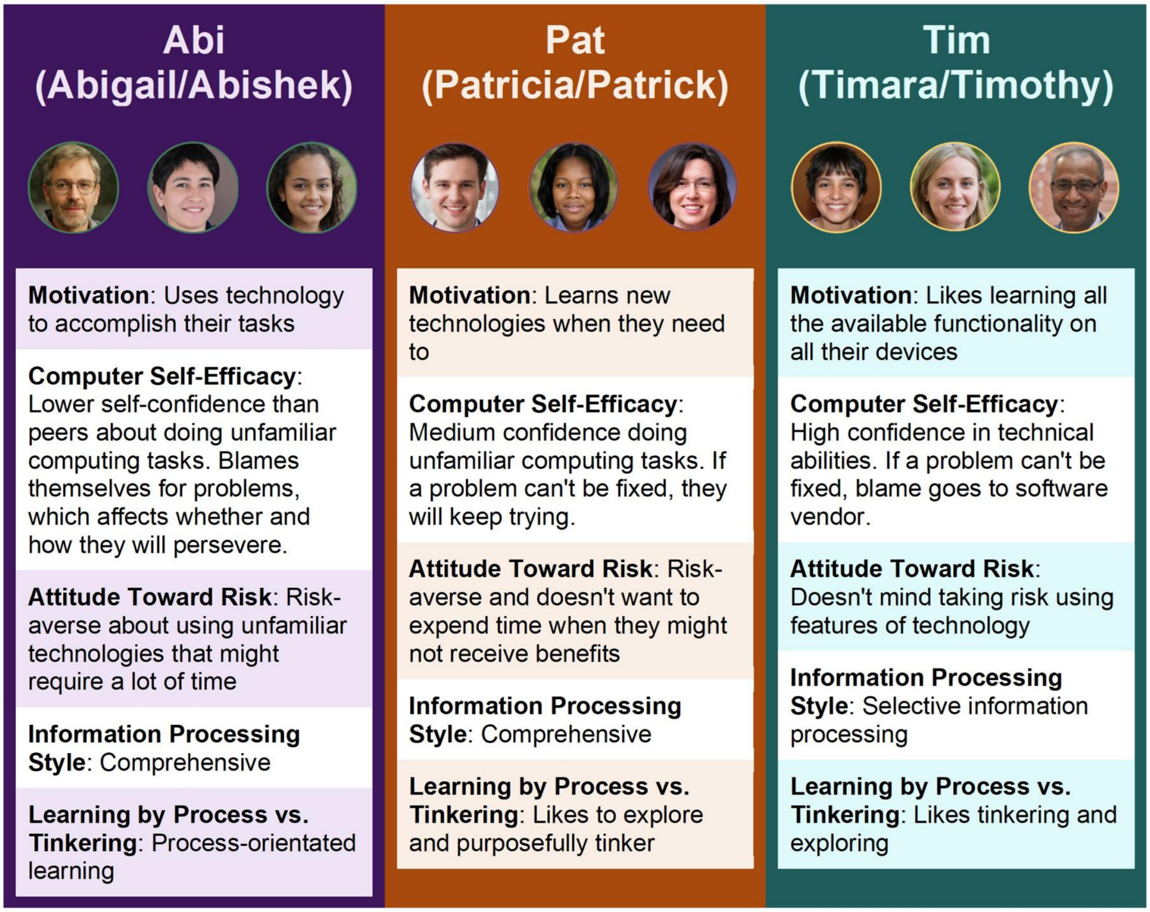


Figure 2. Portions of GenderMag's three personas—Abi (left), Pat (middle), and Tim (right)—as customized by a faculty member who was applying GenderMag to college-level students (Letaw et al., 2021), with each persona's facet value for the GenderMag facet types. (From a type-based perspective, two personas are sufficient to capture the two endpoints of each facet type's range, but more than two personas is useful in emphasizing to other humans the diversity of the target population.)

(Ames et al., 2011; Buolamwini & Gebru, 2018; Rankin & Owensby Thomas, 2020; Ross et al., 2020).

The terms *intersectionality* and *intersectional HCI* are related, but are not exactly the same. As a critical social theory, intersectionality is a framework or theoretical approach that examines the interdependent nature of social identities and inequalities that historically marginalized populations face (Bowleg, 2012; Erete et al., 2018; Rankin & Owensby Thomas, 2020; Schlesinger et al., 2017). In contrast, intersectional HCI is not a critical social theory. Rather, it applies some aspects of intersectionality to technology, emphasizing that many underrepresented individuals have unique life experiences whose impacts on their technology experiences cannot be unraveled by considering a single social identity (Buolamwini, 2017; Fox et al., 2017; Wong-Villacres et al., 2018). For example, intersectional HCI shows how cisnormativity, sexism, racism, and classism extend to users' experiences with and around technology (Andalibi et al., 2022). One recent case study with youth from a lower-income, mostly Hispanic and Black area of Chicago, illustrates the intersectional HCI point well (Harrington & Dillahunt, 2021). The youth were asked to do speculative design and co-design how technology will look in utopian futures—but what they designed had *dys*topian elements because these youth had never experienced a world without racism and poverty.

Intersectional HCI research falls into three categories. The first category, and by far the most frequent in the literature, is *empirically studying* the need for intersectional HCI via qualitative (Andalibi et al., 2022; Ismail & Kumar, 2019; Mangurkar & Rangaswamy, 2022; McFarlane & Redmiles, 2020; Moitra et al., 2021; Rankin & Irish, 2020; Rankin & Owensby Thomas, 2020; Rankin et al., 2021; Thomas et al., 2018; Walker & DeVito, 2020), quantitative (Costello, 2012; Field et al., 2022), mixed-method (Booth et al., 2018; Castelini & Amaral, 2020; Cho et al., 2019; Harrington & Dillahunt, 2021; Prana et al., 2022; Wong-Villacres et al., 2018), and ethnographic (Erete et al., 2020) studies with members of the population of interest. The second category is *developing and/or evaluating concrete technology products* that aim to address the needs of intersectional populations from both general (De Russis et al., 2020; Klumbyté et al., 2022; Schlesinger et al., 2018) and specific perspectives such as gender and skin color (Buolamwini, 2017; Buolamwini & Gebru, 2018), gender and race (Jarrell et al., 2021), race and health conditions (Kim et al., 2022), and gender, race and sexual orientations (Rizvi et al., 2022). The third category and by far the least studied is *analytical research* that examines the complexity of users' experiences across a class of technology and any intersectional population of interest (Boyd et al., 2022; Chen et al., 2022; Smyth & Dimond, 2014).

3.1. Category 1: Empirical studies of the need for intersectional HCI research

Studies in this category intentionally recruit individuals from marginalized social identities or individuals with intersectional identities to shed light on their lived experiences relating to technology experiences. Research investigating the efficacy of computing outreach activities for minority or intersectional students (e.g., high schoolers or undergrads) are common in this category. For example, McFarlane and Redmiles investigated "Get Paid to Program," an after-school program that teaches low-income, high-school women to code, and found it to increase students' computing self-efficacy and refine students' career interests (McFarlane & Redmiles, 2020). Grace Hopper Scholars and the "Glitch Game Tester" are additional examples of outreach programs that have been investigated intensively (Costello, 2012; James DiSalvo et al., 2013; Rankin et al., 2020).

Another approach in this category is a form of experience sampling (Csikszentmihalyi & Larson, 2014; Larson & Csikszentmihalyi, 2014), i.e., collecting tech-pertinent experiences of individuals with intersecting identities (Andalibi et al., 2022; Ismail & Kumar, 2019; Moitra et al., 2021; Rankin & Owensby Thomas, 2020; Rankin et al., 2021; Thomas et al., 2018; Tuli et al., 2019). An example was done during the period with the co-occuring COVID-19 pandemic and escalating attention to systemic racism in the United States (Erete et al., 2020). In this example, the authors' experiences, as Black feminist scholars, help raise awareness in the HCI and CSCW community about systemic oppression. The authors' unique experiences are rooted in their intersectional identities—being a Black feminist in an environment where black and brown communities are disproportionately affected by a worldwide pandemic; at the same time being a Black feminist in a country with persisting systemic racism; and being a Black scholar in tech, a dominantly white field that historically marginalized and erased their experiences. Ismail and Kumar, and Varanasi et al. carried out similar intersectional HCI investigations in low-SES Indian societies where sexism is intertwined with patriarchy and cultural norms (Ismail & Kumar, 2019; Varanasi et al., 2022). Works like these lay the foundations that make later analytical approaches like ours possible.

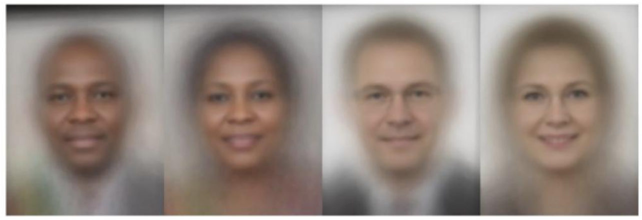
3.2. Category 2: Concrete technology products

Research in this category focuses on developing and/or evaluating a concrete technology product for an intersectional population. A notable example of this category is Joy Buolamwini's thesis featuring the creation and evaluation of Pilot Parliaments Benchmark (PPB), an inclusive benchmark training dataset for intersectional facial recognition algorithms (Buolamwini, 2017; Buolamwini & Gebru, 2018). Buolamwini was one of the first to reveal intersectional differences in accuracy of AI facial recognition algorithms which, as briefly mentioned in the Introduction, tended to be much lower for dark-skinned women than for either women or dark-skinned people (Figure 3). To create PPB, Buolamwini gathered 1270 images to populate each gender/skin color subgroup equally. In conjunction with a binary sex classification, Buolamwini labeled the PPB using the Fitzpatrick skin color classification system (Fitzpatrick, 1988), which has six categories: lighter I-III and darker IV-VI, depending on melanin pigmentation. She then evaluated the accuracy of three AI classifiers (Microsoft, Face++, and IBM) intersectionally using the PPB dataset. Buolamwini showed that giving attention to equal representation in training data in each intersectional group resulted in higher accuracy than other datasets had been able to achieve (Buolamwini, 2017, 2019). Buolamwini also emphasized that at a minimum, it is necessary to report the accuracy of intersectional subgroups because "we cannot assume data collected from one demographic group can be extrapolated to other groups. Even within a demographic group, we need to account for intragroup variation" (Buolamwini, 2017, 2019). Our analytical approach conceptually shares with Buolamwini's approach an emphasis on equally representing all intersectional subgroups, to detect technology's inclusivity issues.

3.3. Category 3: Analytical research

The last category of intersectional HCI research analytically considers both intersectionality's challenges and actions for HCI practitioners. Literature pertaining to this category discusses the potential of multi-dimensional inclusivity, reflects on the challenges of conducting intersectional HCI research, and critiques possible misuses of the term "intersectionality." Schlesinger et al. for example, found that most inclusivity research is single-dimensional and can benefit from incorporating intersectional HCI and reporting the context and demographic information of both researchers and participants (Schlesinger et al., 2017). Similarly, Erete et al. highlighted the importance of understanding the context and self-reflecting on one's biases in research processes (Erete et al., 2018). Wisniewski et al. hosted a CHI'18 Panel in which panelists and the audience recorded best practices and reflected on the challenges of conducting intersectional research (Wisniewski et al., 2018). A few other publications in this category, such as Rankin et al. and Bauer et al. focused on pinpointing where and how other researchers have misused intersectionality by omitting foundations or overlooking important works (Bauer et al., 2021; Rankin et al., 2024; Rankin & Thomas, 2019).

Another approach in this third category stresses the importance of reflexive questions that decision-makers can employ in intersectional HCI. An example of this approach is the "Anti-Oppression Framework" introduced by Smyth and Dimond to guide the understanding and responses to



Gender Classifier	Darker Male	Darker Female	Lighter Male	Lighter Female	Largest Gap
Microsoft	94.0%	79.2%	100%	98.3%	20.8%
FACE++	99.3%	65.5%	99.2%	94.0%	33.8%
IBM	88.0%	65.3%	99.7%	92.9%	34.4%

Figure 3. The accuracy of facial recognition classifiers (i.e., Microsoft, Face ++, and IBM) along social categories (i.e., skin color and gender) highlights disparities. *Note:* that darker-skinned individuals are less likely to be classified than lighter-skinned individuals, and darker-skinned females are less likely to be classified than darker-skinned males and lighter-skinned females (Buolamwini, 2019). (Gender is Buolamwini's terminology, but it refers to biological sex.) Figure downloaded from www.gendershades.org, under Creative Commons License: cc-by-nc-nd, (https://creativecommons.org/licenses/by-nc-nd/4.0/), and slightly modified for clarity by moving face images above the table.

the complexity of the experiences of intersectional users in both the technology HCI practitioners create and the environments in which they design (Smyth & Dimond, 2014). Smyth and Dimond proposed three reflexive questions to guide the technology humans create: What oppression would this work strive to eliminate? At what level (individual, institutional, systematic, cultural)? And at which intersections? Additionally, the framework emphasized that the environment in which HCI practitioners design has to reflect equal identity representation as well as equity measures. Examples of these measures included anti-oppression education and processes for safe conflict resolution at the workplace. Similar to Smyth and Dimond, Rankin et al. emphasized the importance of anti-oppression education and proposed a reading list about intersectionality, revealing its interdisciplinary roots (Rankin et al., 2020). Boyd et al. (2022) developed a tool to support this reflective approach. The tool enables practitioners to enhance their data-based technology products by incorporating comparative intersectional HCI analysis of multi-dimensions such as combinations of age, sex, and race. This approach allows practitioners to visualize and analytically reflect on which intersectional dimensions are included/excluded and why. Smyth and Dimond's, Rankin et al.'s, and Boyd et al.'s analytical approaches aimed to enlighten decision-makers by giving them intellectual means to reflect on what is missing. Our work is in this category, contributing an analytical approach by which HCI practitioners can harness prior foundational work to find their technology's inclusivity issues for intersectional users. Our approach to intersectional HCI, however, does not analyze by identities, but rather enables analysis of diverse personal traits that individuals with diverse intersectional identities may have.

4. Type-based analytical methods to design for intersectional populations

Our aim is to enable HCI practitioners to compose, just in time, their own analyses to analytically consider "inclusivity issues." These issues are the biases present in software that do not support equitable user experience for users with as many multidimensional identities as the practitioners choose to consider.

Our analytical approach is based on types. Because types include every possible value of that type, types bring an equal-data representation property. In contrast, with empirical approaches that depend on the data sampling that was collected, different values of types may be over-represented, under-represented, or omitted entirely, thus biasing the analysis. Still, empirical methods' collected samples can reveal surprising phenomena that type-based methods might not detect. Thus, the equal-data representation property of types at the decision-making level provides a useful complement to empirical methods.

The InclusiveMag family of methods provides an entry point for leveraging type-based reasoning across the full range of values for a type. Types would not work if they attempted to capture users' identities, because identities are too complex. Instead, the InclusiveMag family uses types to capture ranges of *personal traits and preferences* (e.g., their attitudes toward risk (Hekler et al., 2013; Soden et al., 2020)), *not users' identities*. When such types are partial orders that form a bounded lattice (i.e., every subset of values has a unique greatest and least element), they can be represented as a pair of the minimum and maximum possible value of that type. This brings tractability—HCI practitioners can now reason about a principally infinite set of values a type might have by looking at only the two endpoint values. For example, if a feature *simultaneously* supports both those who enjoy risk, and those who most strongly avoid it, then it likely supports everyone's level of risk-aversion in between these two endpoints.

How can we apply InclusiveMag to an intersectional population of possible identities? Prior intersectionality works have shown the insufficiency of the additive approach, for example, analyzing gender and SES separately. But to specifically consider a sufficient sample of all the possible facet value combinations a person could have, one would have to consider the needs of on the order of 2^N kinds of people to handle N traits. Figure 4 illustrates the problem; if a practitioner team who can afford to do a fixed number of investigations tries to consider the needs of individuals with many facet values across many dimensions, their sampling becomes less and less adequate, spread more and more thinly through the multi-dimensional space of possible traits.

InclusiveMag-generated methods do not need multiple empirical investigations with people with different traits (Figure 4(a)). Instead, they work by: (1) identifying facet types (i.e., ranges of possible values of a human trait) that tend to differ (statistically) along some identity spectrum, and (2) pinpointing inclusivity issues that affect people at both ends of each facet type's range of possible values. The analytical approach we describe below extends this technique to multiple dimensions (Figure 4(b,c)). In the following section, we describe the space of intersectional design in terms of sets of facet types, and show that adding dimensions of intersectionality means adding, not multiplying, facet types and values to consider, making intersectional analysis tractable for a practitioner team with limited resources.

4.1. Formalization

We present the mathematical formalization accompanied by a specific running example of a team of HCI practitioners analyzing issues within an application, to enhance user experience equity across genders and SES. This example uses the InclusiveMag notions of *diversity dimensions* along which people may fall, and *facet types*, which define fine-grained personal traits (e.g., a range of people's attitudes toward technological risk, a range of their preferred information processing styles). Figure 2 shows the *diversity dimension* of gender with its *facet types* and their *facet values*. Recall that in Figure 2, Abi's values are endpoints at one end of each facet type's range, Tim's values are endpoints at the other end of each facet type's range, and Pat provides a third set of values.

The following text uses the notions of *diversity dimensions*, *facet types*, and *facet values* to formalize our approach. Each formalization passage is followed by a gray running example of a use case.

Diversity dimension formalization

As explained in Section 2, the InclusiveMag meta-method, which we will abbreviate as iMag, generates for a given diversity dimension $\mathcal{Dim}$ an analytical inclusivity method iMag($\mathcal{Dim}$). Thus, iMag can be viewed as a function parameterized by a diversity dimension that yields an inclusivity method for a specific dimension. For example, GenderMag is generated by applying iMag to $\mathcal{Dim} = \mathcal{Gender}$, so GenderMag = iMag($\mathcal{Gender}$).

Use-case example:
The diversity dimensions in the case of practitioners analyzing the Gender and SES issues present in an app we will call App A are $\mathcal{Dim} = \mathcal{Gender}$ and $\mathcal{Dim}' = \mathcal{SES}$. The corresponding inclusivity methods are GenderMag and SESMag, respectively.

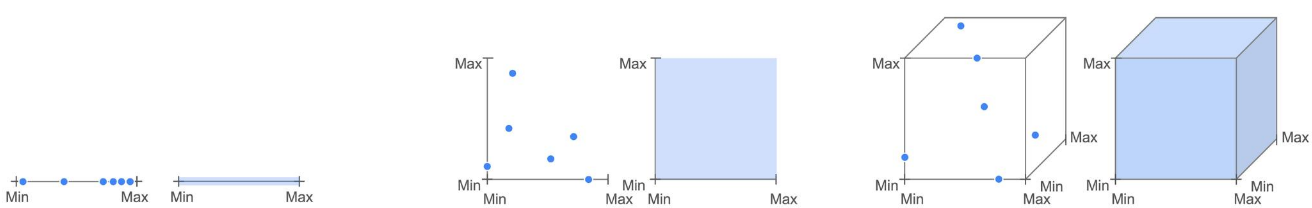
Facet type formalization

iMag does not operate directly on a $\mathcal{Dim}$. Instead, iMag reduces the diversity dimension to its set of facet types. We formalize this by defining each $\mathcal{Dim}$ to be a set of facet types, that is, $\mathcal{Dim} = \{Facet_1, ..., Facet_n\}$. Each facet type $Facet$ is a (partially) ordered set, whose minimum and maximum values are denoted by min($Facet$) and max($Facet$).

Use-case example (cont.):
Using GenderMag's facet types (GenderMag, 2018):
$\mathcal{Dim} =$ { Motivations, Computer Self-Efficacy, Attitude Towards Risk, Information Processing Style, Learning: by Process vs. by Tinkering }.
Using SESMag facet types (Burnett et al., 2024):
$\mathcal{Dim}' =$ { Access to Reliable Technology, Technology Self-Efficacy, Technology Risks, Technology Privacy/ Security, Perceived Control & Attitude Toward Authority, Communication Literacy/Education/Culture }.

Facet values and state set formalization

The purpose of iMag($\mathcal{Dim}$) is to analyze a software use case's inclusivity across the diversity dimension $\mathcal{Dim}$. iMag($\mathcal{Dim}$) works by examining a set of states of the software use case $State = \{state_1, ..., state_n\}$. It examines each state using a pair



(a) Single Dimension (b) Two Dimensions (c) Three Dimensions

Figure 4. The analytical power of a type-based approach. A practitioner team's effort is spread more and more thinly as they spend limited resources to explore an exponentially-growing design space, as in the left entry of each pair of sketches. Types provide equal coverage along each dimension and full coverage of the space, as in the right entry of each pair of sketches.

of contrasting, extreme facet values for each of the facet types. These contrasting extreme values are usually captured by personas. To cover the complete space of all facet values, the two personas are designed so that they each represent the opposite extreme values for every facet type. A $\mathcal{Dim}$-persona is thus defined as a set of facet values $\{facet_1, \ldots, facet_n\}$ with $facet_i \in \{\max(Facet_i), \min(Facet_i)\}$.

Use-case example (cont.):
To analyze App A, the practitioners examine the State set for App A, and use the extreme values for each facet type's $\min(Facet)$ and $\max(Facet)$. The extreme *values* for an iMag($\mathcal{Gender}$) "Learning by Process vs Tinkering" *facet type*, for example, range from Abi's "Process-oriented learning" to Tim's "Likes tinkering and exploring."

How to spot an issue using InclusiveMag formalization

To use iMag($\mathcal{Dim}$) to find inclusivity issues in software, we examine a state $state \in State$ through the lens of an extreme facet value—$\min(Facet_i)$ or $\max(Facet_i)$—and then potentially identify one or more issues of type *Issue*. This single analysis step can be formally represented by a function $spot : Facet \times State \rightarrow 2^{Issue}$ that takes a facet value and a state and returns a set of issues.[3] For a given persona $persona = \{facet_1, \ldots, facet_n\}$, iMag($\mathcal{Dim}$) applies $spot(facet, state)$ for each facet value $facet \in persona$ and state $state \in State$.[4]

To simplify the following definition, we define the function $\overline{spot}$, which identifies all issues for both extreme facet values of a facet type and a particular state.

$$\overline{spot}(Facet, state) = spot(\min(Facet), state) \cup spot(\max(Facet), state)$$

Use-case example (cont.):
For each *state* the practitioners use the lens of an extreme facet value, to identify ("spot") one or more issues of type *Issue* within a *state*. For example, with $\overline{spot}$ (computer self-efficacy,*state*), unexplained or extra information in a *state* could make an Abi-like user with low computer self-efficacy, either spend more time attempting to understand the information or abandon App A. The same unexplained or extra information in the *state* however, might not be an issue to a Tim-like user with high computer self-efficacy.

With $\overline{spot}$ we can now formally define the function iMag, which collects for a dimension $\mathcal{Dim}$ and a set of states *State* all issues identified by $\overline{spot}$. It does so by applying $\overline{spot}$ to all combinations of state and extreme facet values and taking the union of all the results. Note that, when a method is actually carried out for some use case, we parameterize iMag not only by $\mathcal{Dim}$, but also by *State*, the set of states in that use case.

$$\text{iMag}(\mathcal{Dim}, State) = \bigcup_{\substack{Facet \in \mathcal{Dim} \\ state \in State}} \overline{spot}(Facet, state)$$

Use-case example (cont.):
The practitioners simply perform $\overline{spot}$ for each $\mathcal{Dim}$'s extreme facet values, for every state in the use-case. The final results are the union of all instances for which $\overline{spot}$ is used.

To apply the meta-method iMag simultaneously to two dimensions means to apply iMag to the facet types from both dimensions, i.e., the union of both dimensions' facet type sets.

We call this union operation on dimensions, the *join* of two dimensions, since this way of combining dimensions provides a joint view of two diversity dimensions.

$$Join(\mathcal{Dim}, \mathcal{Dim}') = \mathcal{Dim} \cup \mathcal{Dim}'$$

The join of two dimensions represents the entire space of the two dimensions, including their intersection.

Use-case example (cont.):
The team wanted to consider both $\mathcal{Dim} = \mathcal{Gender}$ and $\mathcal{Dim}' = \mathcal{SES}$, so their muti-dimensional results reflect the union of both $\mathcal{Dim}$ and $\mathcal{Dim}'$.

4.2. Compositionality theorem and proof

To analyze an intersectional population characterized by two diversity dimensions $\mathcal{Dim}$ and $\mathcal{Dim}'$, we could apply iMag directly to the joint dimension $Join(\mathcal{Dim}, \mathcal{Dim}')$. But we can just as well combine, that is, take the union of, the result of two independent runs of iMag for the two dimensions $\mathcal{Dim}$ and $\mathcal{Dim}'$, since the following relationship holds.

Theorem 4.1. (Compositionality of iMag)

$$\text{iMag}(Join(\mathcal{Dim}, \mathcal{Dim}'), State) = \text{iMag}(\mathcal{Dim}, State) \cup \text{iMag}(\mathcal{Dim}', State)$$

In the proof of the theorem we make use of the following property of set union that follows directly from the associativity of set union:

$$\bigcup_{x \in A \cup B} f(x) = \bigcup_{x \in A} f(x) \cup \bigcup_{x \in B} f(x)$$

Now we can prove the theorem as follows.

Proof.

$$\begin{aligned}
&\text{iMag}(Join(\mathcal{Dim}, \mathcal{Dim}'), State) \\
&= \text{iMag}(\mathcal{Dim} \cup \mathcal{Dim}', State) && \text{(Definition of } Join) \\
&= \bigcup_{\substack{Facet \in \mathcal{Dim} \cup \mathcal{Dim}' \\ state \in State}} \overline{spot}(Facet, state) && \text{(Definition of iMag)} \\
&= \bigcup_{\substack{Facet \in \mathcal{Dim} \\ state \in State}} \overline{spot}(Facet, state) \cup \bigcup_{\substack{Facet \in \mathcal{Dim}' \\ state \in State}} \overline{spot}(Facet, state) && \text{(Associativity of } \cup) \\
&= \text{iMag}(\mathcal{Dim}, State) \cup \text{iMag}(\mathcal{Dim}', State) && \text{(Definition of iMag)}
\end{aligned}$$

□

4.3. Example: Applying the theorem to concrete values

Suppose an intersectional population of interest is low-socio-economic women. This population lies at the intersection of two diversity dimensions, Gender and SES (socioeconomic status):

$$\mathcal{Dim} = \mathcal{Gender} \qquad \mathcal{Dim}' = \mathcal{SES}$$

producing these definitions:

$$\text{GenderMag} = \text{iMag}(\mathcal{Gender}) \qquad \mathit{SESMag} = \text{iMag}(\mathcal{SES})$$

Substituting these values into Theorem 4.1 says that the union of results of practitioners using the existing GenderMag (Burnett, Stumpf, et al., 2016) and then using an emerging method, SESMag (Burnett et al., 2024), produces the same results as the practitioners would get by using a (hypothetical) new intersectional method "GenderSESMag."

$$\text{iMag}(\mathit{Join}(\mathcal{Gender}, \mathcal{SES})) = \text{iMag}(\mathcal{Gender}) \cup \text{iMag}(\mathcal{SES})$$

or, in other words,

$$\text{GenderSESMag} = \text{GenderMag} \cup \text{SESMag}$$

Note that this example, motivated by the intersectional population of low-SES women, also affords analysis of the other three intersections in this combination of diversity dimensions—low-SES men, high-SES women, and high-SES men. Issues likely to especially impact low-SES women will emerge from practitioners' analysis using "minimum" facet values for each facet type; for high-SES men using "maximum" facet values for each facet type; and so on.[5] Fixing identified inclusivity issues in ways that simultaneously serve both the minima and maxima of each facet type also serves people with a mix of these facet values or with values between them.

Although this example employs two dimensions, extending to additional dimensions is straightforward for any dimension for which an InclusiveMag method exists. For example, extending this example to a three-dimensional intersectional population (e.g., elderly low-SES women) follows the above by simply applying *Join* to a third diversity dimension, $\mathcal{Dim}'' = \mathcal{Age}$, consisting of the facet types that researchers have investigated for AgeMag (McIntosh et al., 2021). The number of dimensions is unlimited, so additional dimensions could continue to be added (e.g., race, country of residence, and so on) to allow increasingly focused intersectional sub-populations.

5. Analytical intersectional HCI in practice: Four use-cases

How might HCI practitioners make practical use of this result on their own? Practitioners can apply the theorem "forward," in the split/decomposition direction, to create a plan for analysis. Then, the practitioners can apply the theorem "backward," in the join/composition direction, to take the union of—i.e., accumulate into a single list—the inclusivity issues detected in the above analyses. These applications of the theorem give rise to (at least) four practitioner use-cases.

5.1. Use case #1: Intersectional evaluations

An obvious application of the theorem is that HCI practitioners can evaluate their products one diversity dimension at a time, while still covering the entire intersectional space of an intersectional population.

For example, a practitioner trying to address the needs of elderly, low-SES women, can analyze their prototype via AgeMag (McIntosh et al., 2021), then via SESMag (Burnett et al., 2024), then via GenderMag (Burnett, Stumpf, et al., 2016). The practitioner can then compose (take the union of) the issues found separately with AgeMag, SESMag, and GenderMag, to obtain inclusivity issues that elderly women in low socio-economic situations will face, as well as those faced by people in the other intersections of these three diversity dimensions.[6] Accumulating the results in this way is justified by applying the theorem backward.

5.2. Use case #2: Divide-and-conquer by a team or teams for complex evaluations

By the same token, a team or teams of HCI practitioners could divide-and-conquer a multi-dimensional analysis by splitting it into different dimensions, with different subteams doing the analysis on the different dimensions. For example, one team might do the AgeMag analysis while another does the GenderMag analysis, and so on. In fact, a team could even divide up the work of a single InclusiveMag analysis. For example, one subteam might do an analysis in terms of only the first three facet types, with another subteam focusing on the remainder of the facet types. Doing so might help ward off the facet popularity phenomenon, in which a team habituates to considering certain facet types and tends to neglect others (as reported in Burnett, Peters, et al., 2016). Splitting a complex analysis into several simpler analyses that are run independently of one another, followed by composing the results, is justified by applying the theorem forward and then backward.

5.3. Use case #3: Combining facet-based artifacts from multiple diversity dimensions

HCI practitioners could build formative and thought-exercise artifacts directly from InclusiveMag-generated facet types and/or facet values. For example, HCI practitioners at some companies have used a GenderMag "facet survey" (Hamid et al., 2024) to gather formative data about the facet-value composition of their customer bases (Anderson et al., 2024; Guizani et al., 2022; Hilderbrand et al., 2020; Vorvoreanu et al., 2019). Note that combining such survey questions from more than one diversity dimension—i.e., the union of such questions—adds to the length of the survey at a rate proportional to the number of facet types, which may be acceptable for some surveys.

Some HCI practitioners have also used facet types and values directly as the basis for design heuristics and design examples specialized to one or a few diversity dimensions (e.g., GenderMag, 2021; Letaw et al., 2021; Mendez et al., 2019; Microsoft Design, 2018). HCI practitioners can combine such heuristics and design examples as a straightforward union operation of the facet types that define each of the dimensions of interest.

Trust in the validity of all these practices is justified by the backward or compositional direction of the theorem.

5.4. Use case #4: Invite more personas to design meetings

Some uses of InclusiveMag methods revolve around the personas that have been created around the facet types (recall Figure 1). For example, following the recommendations of persona researchers such as Adlin and Pruitt, one persona-based practice is HCI practitioners "inviting" their personas to design meetings (Adlin & Pruitt, 2010), such as seating pictures of each persona around the meeting's conference table, and considering the persona's (expected) opinion as design decisions are being made. This practice is easily expanded by inviting two personas from every diversity dimension of interest. For example, instead of inviting just the two personas that together capture all the maximum and minimum values of the facet types in one dimension, invite two personas like these from every diversity dimension of interest.

The addition of persona pairs to a design session is equivalent to performing multiple analyses for different dimensions in parallel and combining the results from all analyses just in time. Formally, this scenario is equivalent to the divide-and-conquer scenario. In fact, it could be considered an extreme version of divide-and-conquer in which each individual facet type from any dimension is covered for each state of the software use case.

5.5. Beyond these four

Additional use-cases relating and leveraging the above are also possible, such as optimizations to avoid analyzing a facet type shared by multiple dimensions multiple times, leveraging past analyses of some diversity dimension (e.g., Gender only and Age only) to obtain new insights into intersectional populations, and using facet surveys to recruit empirical populations that give equal empirical voice to every intersectional population.

6. Empirical case study: The approach in practice

To see how the theorem would manifest with practitioners, we conducted a mixed-method empirical case study with 10 HCI teams (24 participants) on Section 5's Use-case #2—different groups of HCI practitioners evaluating one diversity dimension each and then composing the analytical results (i.e., applying the theorem forward, then backward).

Our case study investigated three diversity dimensions and their intersections. The intersectional population of particular interest to us was low-SES immigrant women. Since InclusiveMag is about supporting *both* endpoints of facet values, we were also interested in this population's intersectional "opposite": high-SES nonimmigrant men. These intersectional populations were in the intersection of three diversity dimensions: SES, Immigration, and Gender.

$$\mathcal{D}im = \mathcal{SES} \qquad \mathcal{D}im' = \mathcal{I}mmigration \qquad \mathcal{D}im'' = \mathcal{G}ender$$

Using these three dimensions and their intersection, we investigated *how well HCI practitioners' use of the approach matched the theorem's predictions.*

$$\begin{aligned}&\text{iMag}(\mathcal{J}oin(\mathcal{SES}, \mathcal{I}mmigration, \mathcal{G}ender))\\&\quad\subseteq \text{iMag}(\mathcal{SES}) \cup \text{iMag}(\mathcal{I}mmigration) \cup \text{iMag}(\mathcal{G}ender)\end{aligned}$$

which simplifies to:

$$\begin{aligned}\text{SESImmigrationGenderMag} \subseteq (&\text{SESMag} \cup \text{ImmigrationMag}\\&\cup \text{GenderMag})\end{aligned}$$

Note that for this study, we are investigating a slightly weaker claim than the theorem makes—we have replaced the theorem's equality prediction ($=$) with a subset claim ($\subseteq$). The theorem says that evaluating each diversity dimension as per the InclusiveMag-generated method for that dimension should give the exactly same results as evaluating the intersectional dimension using an InclusiveMag-generated method for it, but it does not account for humans' varying degrees of perfection when doing these evaluations. Since humans tend to be imperfect in different ways, here we consider whether the union of the HCI practitioners' results analyzing one dimension at a time would provide *at least* the same results (and possibly more) as from the HCI practitioners analyzing the intersectional cases, accounting for the possibility that one team working on a more complex domain is more likely to make errors of omission than three separate teams each working on simpler, one-dimensional domains.

6.1. Methodology

To perform this investigation, we needed four InclusiveMag-derived methods—one for each of the SES, immigration, and gender dimensions and one for the intersectional SES+immigration + gender dimension. We needed software to evaluate, which in our case was a prototype of a Hands-Free Integrated Development Environment (IDE). We also needed evaluations of this prototype based on the products of InclusiveMag-derived methods. Finally, we needed HCI researchers, designers, and practitioners to create and use these items.

Our specific research questions were:

For HCI practitioners who do not have resources to do empirical work with their populations:

- (RQ1): *Can the bugs*[7] *found analytically by an intersectionally-aware HCI practitioner team also be found analytically by at least one of the HCI practitioner teams for the component diversity dimensions?*
- (RQ2): *If an intersectionally-aware HCI practitioner team analytically finds a bug, will the facets they use also be*

used by at least one of the HCI practitioner teams for the component diversity dimensions, to find that same bug?

6.1.1. Participants

We recruited 24 participants from current and former offerings of a 10-week, advanced HCI (Inclusive Design) course for graduate and 4th year undergraduate HCI students. Being in a course gave participants a pre-existing reason to work for weeks on these tasks, namely, getting a "good enough" course grade per their standards. We chose this particular course because in the course, students learn inclusive design skills hands-on using InclusiveMag. Specifically, over the 10-week course, they use InclusiveMag's Steps 1–2 to create their own inclusive design methods and then use the methods they created to evaluate the inclusivity of prototypes they are designing (InclusiveMag's Step 3). Thus, all participants were familiar with the InclusiveMag family of methods. About 30% of the participants also had real-world HCI experience. The 24 participants had diverse intersecting identities across ethnicity, race, cultures, nationalities, residency status, SES, and gender.

All participants consented to participate by signing IRB-approved informed consent forms. In addition, they explicitly consented to our use of work products they had created before the study officially began. The latter was a necessary addition because participants were in the course at different times (offerings between 2017 and 2022), some of which predated our study.

The 24 participants acted in three roles: *researcher-participants* to create InclusiveMag-derived methods for different diversity dimensions, *practitioner-participants* to use those methods to evaluate a prototype, and a *designer-participant* to provide that prototype and an appropriate workflow for using it. For the *researcher-participants* we followed a classic case study methodology (De Russis et al., 2020), in which there were no controls—participants did whatever they did in their own context to research the diversity dimensions. The *practitioner-participants* used the products of the *researcher-participants* following specialized cognitive walkthroughs to reason their way through an evaluation of a prototype.

6.1.2. The researcher-participants' work

The researcher-participants' mission was not to reveal answers to RQ1 and RQ2. Rather, it was to provide, in an ecologically valid manner, the methods by which the practitioner-participants (Subsection 6.1.3) would search for inclusivity bugs in the interface, to enable us to answer RQ1 and RQ2.

Toward that end, the researcher-participants (9/24 of the participants) worked in two teams (Immigrant-R and Intersect-R) of 4–5 people each, in which they followed InclusiveMag's Steps 1–2 to construct analytical methods with facets and research-based personas for the diversity dimensions of Immigration and SESImmigrantGender, respectively. The teams spent 8–10 weeks of the course doing this work, which is as much time or more than many UX researchers can spend on population research (Gonzalez et al., 2017; Stone et al., 2016).

To carry out InclusiveMag's Steps 1–2, Teams Immigrant-R and Intersect-R performed extensive research (however they saw fit, per case study methodology (Runeson et al., 2012)) so as to create whatever facet types emerged from their research. Teams Immigrant-R and Intersect-R used various research methods, including interviews; published blogs and youtube-based interviews/documentaries with/about their populations; reviews of academic literature; and drawing upon the lived experiences of team members who self-identified as members of the population they were investigating. In addition, since Team Intersect-R was researching an intersectional population, they also informed their research with Team Immigrant-R's findings and with the GenderMag and SESMag foundational research. Team Immigrant-R's work resulted in an ImmigrationMag method whose facets formed the core of personas Ahava and Bernadette; likewise, Team Intersect-R's work resulted in an SESImmigrationGenderMag method with personas Jesse and Taylor (Figure 5).

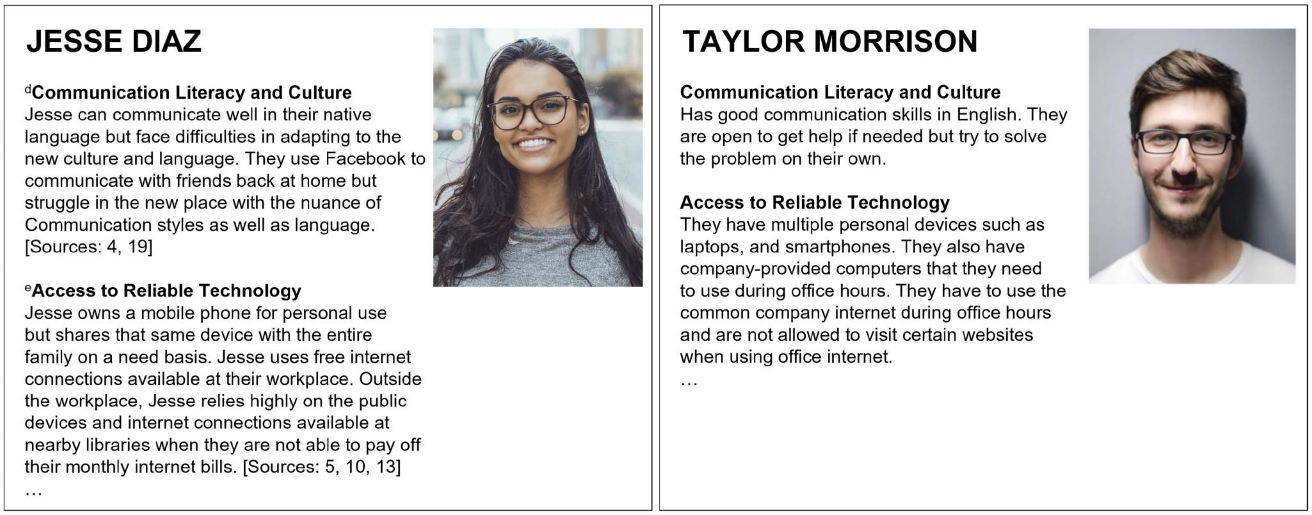
The other two diversity dimensions in the study were gender and SES. For the gender dimension, we used GenderMag (Burnett, Stumpf, et al., 2016), whose ecological validity stems from its use by practitioners at several organizations (e.g., Burnett et al., 2017; Hilderbrand et al., 2020; Vorvoreanu et al., 2019). For the SES dimension, we used Burnett et al.'s facets (Burnett et al., 2024), which had been created by a team of HCI researchers that included several with professional HCI experience; we then created personas based on those facets for purposes of this study.

All four researcher teams chose the cognitive walkthrough for the analytical process, so their analytical methods all integrated the facets and personas into specialized cognitive walkthrough processes. Table 1 lists the researcher-participants' teams, the diversity dimensions they worked with, what facets they included, and which personas brought the facet endpoints to life. All personas are also included in the Supplemental Documents.

The teams' particular definitions of the facets showed that the facets frequently overlapped, as the Supplemental Documents detail. Tables 1 and 2 together show how all the facets the Intersect-R team ultimately created corresponded to a facet for at least one single-dimension population, although their terminology sometimes varied. For example, the Intersect-R facet *Communication Literacy and Culture (Commun.)* was similar to the SES facet *Communication Literacy/Education/Culture (Commun.)* and the Immigrant-R facet *Level of English Language Proficiency (Commun.)*. All three of these *Commun.* facets covered the persona's ability to communicate using cultural references and jargon, read comprehensively, and speak English as a primary or second language. The complete definitions of the facets and the correspondences among them can be found in the Supplemental Documents.

6.1.3. The practitioner-participants' and designer-participant's work

Given the analytical methods they inherited, the mission of the 17 practitioner-participants (three of whom had also been



(a) (b)

Figure 5. Excerpts from personas that Team Intersect-R created to represent (a) Low-SES Immigrant Women and (b) High-SES Nonimmigrant Men. (The sources and footnotes refer to that team's internal documents, not sources/footnotes in this paper.)

Table 1. Which participants did what.

Researcher team	Diversity dimension	Facets	Endpoint personas	Practitioner team
Burnett et al. (2024)	SES	Access to Reliable Technology (Access); Technology Self-Efficacy (SE); Technology Risks (Risks); Technology Privacy/ Security(Priv.); Perceived Control & Attitude Toward Authority (Control); Communication Literacy/Education/Culture (Commun.)	Low-SES: Dav, High-SES: Fee	SES-P1, SES-P2
Immigrant-R	Immigration	Level of English Language Proficiency (Commun.); Willingness to Accept Help (Accept Help); Mental Health/Past Trauma (Mental Health); Comfort using Technology (SE)	Immigrant: Ahava, Nonimmigrant: Bernadette	Immigrant-P1, Immigrant-P2
GenderMag (2018)	Gender	Motivations (Mot.); Computer Self-Efficacy (SE); Attitude Towards Risk (Risks); Information Processing Style (Info. Proc.); Learning: by Process vs. by Tinkering (Learn)	Women: Abi, Men: Tim	Gender-P1, Gender-P2
Intersect-R	Immigration, SES, Gender	Communication Literacy and Culture (Commun.); Access to Reliable Technology (Access); Risks, Privacy, Security (Risks); Perceived Control and Attitude Toward (Control); Information Processing Strategies (Info. Proc.)	Immigrant Low-SES Women: Jesse, Nonimmigrant High-SES Men: Taylor	Intersect-P1, Intersect-P2

The first four columns list the research-participants' teams and these products they produced. The last column lists the practitioner-participants teams that used the InclusiveMag-derived products.

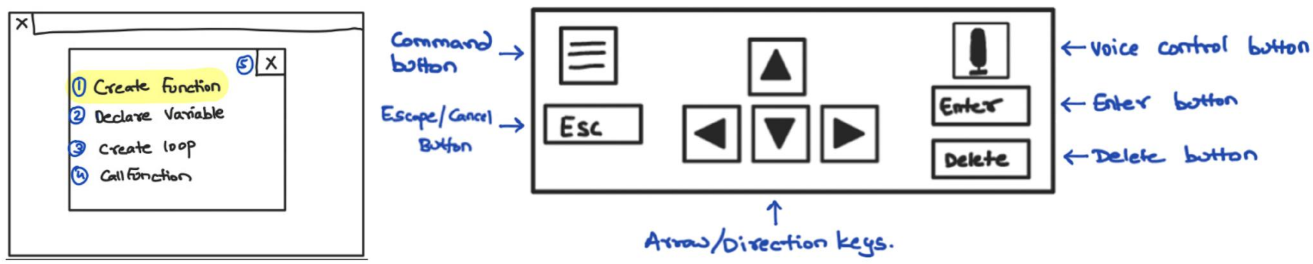
Table 2. The facets the researcher teams created for each diversity dimension.

Researcher team	Facets						
Burnett et al. (2024)	Commun.	Access	Risks, Priv.	SE, Control			
Immigrant-R	Commun.			Accept Help, SE			Mental Health
GenderMag (2018)			Risks	SE	Info. Proc., Mot.	Learn	
Intersect-R	Commun.	Access	Risks	Control	Info. Proc.		

Each row shows the matched facets across dimensions.

researcher-participants) was to apply their respective methods and evaluate the inclusivity of a prototype. Their work processes and products were the data we used to answer RQ1 and RQ2.

Thus, the practitioner-participants worked in 8 teams (2–3 people per team), using the researcher-participants' InclusiveMag-derived products to analytically evaluate the personas' user experiences with an IDE prototype, which incorporated a foot-operated keyboard for disability support. The designer-participant chose that IDE prototype because they had been a UI designer of it. Given this background, the designer-participant was then able to serve as the expert on the prototype and its intended workflow. Table 1's rightmost columns list the teams



(a) (b)

Figure 6. Excerpts of the Hands-Free IDE. (a) The IDE screen displaying a menu with the "Create Function" option selected. (b) The foot-keyboard which enabled users to navigate cursor position, push buttons, tell the system to listen for voice commands, etc.

of practitioner-participants with the persona they worked with to perform their evaluations of that prototype and its workflow.

The practitioner-participants teams' evaluations of the IDE prototype (InclusiveMag's Step 3) were cognitive walkthroughs specialized to the facets of the diversity dimension a team was working with. For these cognitive walkthroughs, they walked through an action sequence of the prototype from the perspective of their personas and facets, asking before each action whether their persona would do that action, and after each action whether their persona would feel like they were making progress.[8]

The action sequence, which the designer-participant had provided, was: (1) press the "command" button on the foot-keyboard, (2) press the "voice" button on the keyboard, (3) say "1," (4) press the "enter" button on the keyboard, (5) say "1," (6) say "AddFunction" to name the function, and (7) press the "enter" button on the keyboard. This sequence of seven actions allowed users to create a function using voice commands. Figure 6(a) shows the IDE's screen early in this sequence, after a user says "1" to select the "create function" option. Figure 6(b) shows the foot-keyboard input device.

The designer-participant also customized all personas' background information to ensure appropriateness for IDE usage, as follows:

> [Persona] is 17 years old. [Persona] is in their last year of high school. [Persona] is living with their parents. [Persona] is comfortable with technology, and their hobby of coding has led them to want to study computer science in their dream college.

The teams of practitioner-participants wrote down their evaluations for each action in the sequence, using a walkthrough form that consisted of 7 pre-action and 7 post-action questions. The pre-action questions were "Will ¡persona¿ do this step? (yes/maybe/no, what facets, and why)." The post-action questions were "If ¡persona¿ does the right thing, will they know that they did the right thing and is making progress toward their goal? (yes/maybe/no, what facets, and why)." For example, Figure 7 shows how Team Gender-P1 answered Action 1's pre-action question. The forms the teams used and the prototype workflow they evaluated are included in the Supplemental Documents.

6.1.4. What counted as a bug

We declared a pre- or post-action to be a *bug* if anyone on the team identified a problem—i.e., if Maybe or No had been checked off (Figure 7), even if Yes had also been checked off. As in other works (e.g., Burnett, Peters, et al., 2016), we defined a bug as also being an *inclusivity bug* if the team wrote that the bug was tied to one of the persona's facet values because that would suggest that the bug would arise disproportionately often for people with that facet value. Note that there could be only one bug per pre- or post-action; multiple explanations or difficulties surrounding that pre- or post-action were considered part of the same bug.

The teams had two ways they could mention facet values during their walkthroughs. First, they could simply check off a facet (Figure 7(c)). Alternatively, they could write about it in the free-text part of the form (Figure 7(d)). To identify facet values mentioned in the 109 free-form text entries the teams had made, we used qualitative coding. Two researchers independently coded 20% of the free-form text data. Their agreement level was 97.78% (Jaccard index), indicating a very high level of agreement. Given this agreement level, one researcher coded the remaining data.

6.2. Results

6.2.1. RQ1: Did the intersectionally-aware practitioner-participants teams find anything the single-dimension teams didn't?

RQ1 asks whether the bugs the intersectionally-aware practitioner-participants teams found analytically were the same bugs that at least one of the single-dimension teams found analytically. The answer for these practitioners was "mostly." Figure 8 shows the teams' answers to the 28 analytical questions. In four, the teams all agreed that no inclusivity bugs were present for their populations, leaving 24 in which at least one team found an inclusivity bug. As the checkmarks in each table's last row show, the composition of the single-dimension practitioner-participants teams' analytical work identified 23 of these 24 inclusivity bugs and agreed on the 4 bug-free questions, thus outperforming any one team—including the intersectionally-aware teams.

We calculated the subset results (the last row in 8a and 8c) by using the previous relation (SESImmigrationGenderMag ⊆ SESMag ∪ ImmigrationMag ∪ GenderMag) with the following three criteria:

Criterion 1: If at least one single-dimension team found the same bug as the corresponding intersectionally-aware

Action #1 : Presses the | | | command button using their feet a

(e.g., Tap 'Browse Off'.)

1a. [BEFORE ACTION] Will <persona> do this step? Why?

☐ Yes	✓ Maybe	✓ No	b
Which, if any, of <persona>'s facets did you use to answer the question?			
☐ *Motivations* ☐ *Computer Self-Efficacy* ☐ *Attitude Toward Risk* ☐ *Information Processing Style* ☐ *Learning: by Process vs. by Tinkering* ☐ *None of the above*	☐ *Motivations* ☐ *Computer Self-Efficacy* ☐ *Attitude Toward Risk* ✓ *Information Processing Style* ☐ *Learning: by Process vs. by Tinkering* ☐ *None of the above*	✓ *Motivations* ☐ *Computer Self-Efficacy* ✓ *Attitude Toward Risk* ☐ *Information Processing Style* ✓ *Learning: by Process vs. by Tinkering* ☐ *None of the above*	c
Why?	*Why?* It looks like a menu button, therefore because of their information processing style, they might press it to get more information.	*Why?* They are not aligned to tinker. Since their goal is to use voice control, they will use that instead because of their motivations and learning style (by process). The command button does not signify what it is going to be used for. They also don't want to break anything and do the wrong thing by pressing the button.	d

Figure 7. Team Gender-P1's Walkthrough Form for Action 1's pre-action question. (a) The action the team is evaluating. (b) The answers (yes/maybe/no) to the pre-action-1 question. (Since not all members of Team Gender-P1 agreed on the answer, they selected both Maybe and No.) (c) The facets the team members used to decide their answers. (d) What Team Gender-P1 wrote about their reasoning.

team, then the subset relationship holds. 15 of the total 28 analytical questions satisfied Criterion 1 (Figure 8(a): 1a, 1b, 2a, 2b, 3a, 4a, 4b, 5a, 6a, 7a; (c): 2b, 3a, 4b, 5a, 7a). For example in column 2a of Figure 8(a), both Teams Gender-P1 and Intersect-P1 reported a bug; since at least one of the other teams found the same bug that Intersect-P1 found, Criterion-1 is satisfied.

For example, the particular inclusivity bug in Column 2a arose just before the persona needs to press the "voice" button. Team Gender-P1 found that their persona, Abi, would need to tinker around to find the button; but tinkering is not in line with Abi's process-oriented learning style:

Gender-P1: … [Abi] is not a tinkerer, would not like to press the button. [Abi] might want to press "ESC" to go back and look for more information/help.

Team Intersect-P1 also found that situation to have an inclusivity bug; they were not convinced that their persona, Jesse, would be confident in associating the microphone icon with voice commands:

Intersect-P1: This button looks familiar with other popular applications. But not entirely sure, if [Jesse] may have the idea about a feature that has something to do with voice.

Criterion 2: If at least one single-dimension team found a bug but the corresponding intersectionally-aware team missed it, the subset relationship still holds. 8 of the total 28 analytical questions fulfilled Criterion 2 (Figure 8(a): 5b, 6b; (c): 1a, 1b, 2a, 3b, 4a, 5b). In column 5b in Figure 8(c), for example, Team Gender-P2 reported a bug, but Team Intersect-P2 did not. This meets Criterion 2 because here the union of the three single-dimension teams have done at least as well at bug-finding as the intersectionally-aware team.

For example, the particular bug in Column 5b arose after the persona has said "1." Team Gender-P2 found that the persona, Tim, would face an inclusivity bug understanding the IDE's response:

Gender-P2: … It is not certain that [Tim] will know [they are making progress toward their goal] because [Tim] needs to try other options to understand the [IDE].

However, Team Intersect-P2 did not find a bug there; they trusted the screen would be self-explanatory for their persona, Taylor:

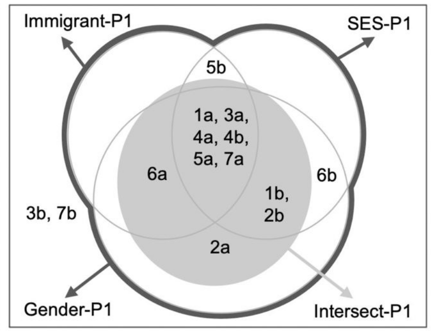
Intersect-P2: The options displayed on the screen are self-explanatory for [Taylor] as they are comfortable with using technology and technological terms …

These teams' findings still satisfy the subset relationship: the union of single-dimension teams' bug-finding at this stage was *at least* as "good" as Intersect-P2 at bug-finding.

Criterion 3: If all teams agreed that there was no bug with a pre- or post action question, the subset relationship holds. 4 of the 28 analytical questions fulfilled Criterion 3 (Figure 8(a): 3b, 7b (c): 6b, 7b). Column 7b in Figure 8(c) is one example: neither Team Intersect-P2 nor any of the single-dimension teams found a bug. 7b represents the state of the prototype just after the persona had pressed enter to

Team/Action	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	Total Bugs
SES-P1	*	*		*	*		*	*	*	*		*	*		10/14
Immigrant-P1	*				*		*	*	*	*	*		*		8/14
Gender-P1	*	*	*	*	*		*	*	*		*	*	*		11/14
Intersect-P1	*	*	*	*	*		*	*	*		*		*		10/14
Subset?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

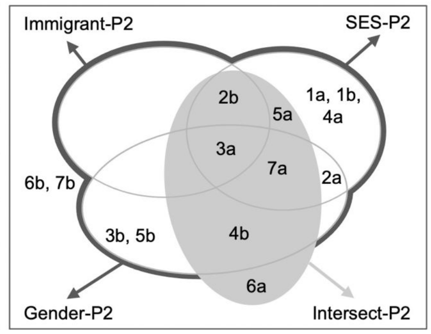
(a) Low-SES Immigrant Women



(b) Low-SES Immigrant Women

Team/Action	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	Total Bugs
SES-P2	*	*	*	*	*		*		*				*		8/14
Immigrant-P2				*	*										2/14
Gender-P2			*		*	*		*		*			*		6/14
Intersect-P2				*	*			*	*		*		*		6/14
Subset?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	

(c) High-SES Nonimmigrant Men



(d) High-SES Nonimmigrant Men

Figure 8. RQ1 results: (Top): for all 14 of the Low-SES Immigrant Women's analytical questions, the composition of the single-dimension teams' answers found inclusivity bugs whenever the intersectionally-aware team did. (Bottom): This was also true for 13/14 of the High-SES Nonimmigrant Men's analytical questions. (Tables, Left): Bugs each team reported for each of the 7 pre-action questions (a's in the table's columns) and post-actions questions (b's in the table's columns). $*$: The team reported a bug in the analytical question. (Figures, Right): The extent to which the intersectionally-aware teams' findings (shaded) were a subset of the union of the bugs the single-dimension teams found (thick black outline).

create the function. Immigrant-P2, for example, found that their persona, Bernadette, would know they had been successful at creating the function:

Immigrant-P2: [Bernadette]'s initial goal was to create a function with voice control. Once [Bernadette] sees this screen, [Bernadette] will know the function has been created successfully.

Team Intersect-P2 came to the same conclusion, since their persona, Taylor, is used to working with IDEs:

Intersect-P2: As [Taylor] is comfortable with using technology and have high perceived control over technology, [Taylor] will feel good about [accomplishing the task].

The team's agreement about the absence of a bug with 7b satisfies the subset relationship.

If none of the these criteria were met, the subset relationship did *not* hold. Only one of the 28 analytical questions, column 6a in Figure 8(c), did not fulfill the criteria. 6a represents the state of the prototype just before the persona had to say "AddFunction" to name the function. Team Intersect-P2 thought their persona would use other terms instead:

Intersect-P2: maybe, [Taylor] might even say different words related to this like "create function", "begin function", … etc because as [Taylor] use different technologies, [Taylor] are used to seeing different tech words across platforms.

But are these inclusivity bugs valid? Prior empirical evidence suggests that they are. The InclusiveMag methods presented here are all use variants of the cognitive walkthrough. From this relationship with other members of the cognitive walkthrough family, the iMag($\mathcal{Dim}$) methods inherit an extremely good true positive rate—90% and higher (Mahatody et al., 2010). This means that if a practitioner uses a member of the cognitive walkthough family to find a usability problem, there is a 90% or higher probability that a user somewhere will actually experience that problem, as Mahatody's survey of empirical evidence shows (Mahatody et al., 2010). Investigations of GenderMag's true positive rates, iMag($\mathcal{Gender}$), confirm Mahatody's results, with empirical true positive rates of at least 95% on the inclusivity bugs found (Burnett, Stumpf, et al., 2016; Guizani et al., 2022; Padala et al., 2022; Vorvoreanu et al., 2019). On the other hand, false negatives—errors of omission, in which a practitioner fails to analytically spot an inclusivity bug—are common in members of the cognitive walkthrough family (Mahatody et al., 2010), and there is no reason to believe that InclusivityMag-generated methods would be an exception.

This background on true/false positives/negatives suggests that the inclusivity bugs the practitioner teams found in our study are very likely (at least 90% likely) to be real bugs, but the teams probably did not find all the inclusivity bugs that will arise for the intended intersectional populations. Put another way, the results these teams found are very likely to be sound (genuine inclusivity bugs for the intersectional populations). And although the results are *un*likely to be complete, the single-dimension teams' combined results achieved more completeness—i.e., found more of the inclusivity bugs (23 vs. 16)—than the intersectionally-aware teams did. We will discuss completeness further in Section 7.

6.2.2. RQ2: How did the practitioner-participants teams find the inclusivity bugs they found?

In the InclusiveMag family of methods, the process of reasoning about inclusivity bugs centers on participants' application of their current persona's facet values. For example, recall persona Jesse, shown earlier in Figure 5(a). Jesse's facet value for the *Access* facet is that Jesse relies mostly on shared/public devices and free/public internet sources. Team Intersect-P1's walkthrough form indicated that they used this facet value to identify an inclusivity bug at Column 2a in Figure 9(a). Thus, one lens on how the teams' bug-finding reasoning may have been the same or different from one another is to compare the intersectionally-aware teams' use of *facet values*. For this analysis we consider only the 15 bugs found in with both the intersectionally-aware team and a single-dimension team found the same inclusivity bug (i.e., those satisfying Criterion 1).

For the most consistency with the theorem, ideally the result of our analysis would show a subset relationship in terms of facet reasoning—i.e., each intersectionally-aware team's use of facet values would turn out be a subset of the facet values used by the combined related single-dimension teams. And as Figure 9(a) shows, this subset relationship usually held. Specifically, teams who considered the underrepresented populations (the P1 teams) almost always satisfied this subset relation (9/10 times) in their use of the facet values (Figure 9(a)), and the P2 teams did so almost as often (4/5 times) (Figure 9(b)).

For example, consider column 7a in Figure 9(a), for which all P1 teams had identified an inclusivity bug. Column 7a represents the state of the prototype just before pressing the "enter" button to create the addition function. The three single-dimension teams together associated the bug with a total of five facets: *Learn*, *Commun.*, *Info.Proc.*, *Risks*, and *Control*. The Intersect-P1 team associated the bug with a subset of these, *Info.Proc.*, *Risks*, and *Control*. Team Intersect-P1 used these three facets to reason that the persona, Jesse, had performed several actions but was still uncertain they were making progress toward creating the function:

Intersect-P1: [Jesse] made a lot of progress. Without concrete clue it will be very tough to be confident.

Team Immigrant-P1 attributed the bug to two facets, *Commun.* and *SE*, the latter similar to Team Intersect-P1's *Control* facet. They reasoned that Ahava's low self-efficacy might make the persona hesitant about switching input modalities:

Immigrant-P1: …if [Ahava] are using voice control, [Ahava] might be hesitant to go back and forth between the foot and voice commands

Team/Action	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b
SES-P1	Risks SE Control Commun.	SE		SE Commun.	SE Control		Commun. None	Commun.	Risks Priv. Control				SE Priv. Control	
Immigrant-P1	Accept Help				Commun. SE		Commun. SE	Commun. Accept Help SE	Accept Help SE		Commun. SE		Commun. SE	
Gender-P1	Mot. Info.Proc. Risks Learn	Mot. SE Risks Learn	Mot. Info.Proc. SE Risks Learn	Mot. Info.Proc. SE Risks None	Mot. Info.Proc. SE Risks None		Mot. Info. Proc. Risks Learn	SE Risks Learn	Mot. Info.Proc. SE Risks Learn None		Info.Proc. Risks Learn		Info.Proc. SE Risks Learn None	
Intersect-P1	Info.Proc.	Info.Proc.	Access Info.Proc. Control	Commun. Info.Proc.	Info.Proc.		Risks Control	Risks	Info.Proc.		Info.Proc. Control		Info.Proc. Risks Control	
Subset of Facets?	Subset	Subset	Not Subset	Subset	Subset	N/A	Subset	Subset	Subset	N/A	Subset	N/A	Subset	N/A

(a) Low-SES Immigrant Women

Team/Action	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b
SES-P2				Access SE	Access Commun.				Commun. Access SE Risks				None	
Immigrant-P2				Commun. SE	Commun. SE									
Gender-P2					Mot. Learn			Mot. Learn					Mot. Learn	
Intersect-P2				None	Control			Info.Proc.	None				Info.Proc. Control	
Subset of Facets?	N/A	N/A	N/A	Subset	Subset	N/A	N/A	Subset	Subset	N/A	N/A	N/A	Not Subset	N/A

(b) High-SES Nonimmigrant Men

Figure 9. RQ2 results: Whenever an intersectionally-aware team found an inclusivity bug, were the facets they used the same as those the single-dimension team used? (Facet colors show facets similar to the intersectionally-aware team's, as per Table 2.) (Top): Yes for Low-SES Immigrant in 9/10 cases. (Bottom): Yes for High-SES Nonimmigrant Men in 4/5 cases.

Team Gender-P1 used three similar facets to Team Intersect-P1, (*Info. Proc.*, *SE*, and *Risks*), as well as an additional facet, *Learn*, to highlight the issue of frequent switching between the input modalities:

Gender-P1: [Abi] will use VOICE, and probably say "2" instead of going back to the keyboard. [Abi] will use the same process as before.

A similar facet-subset relation held for the P2 teams (Figure 9(b)). For example, Teams Intersect-P2 and SES-P2 found a bug in column 2b, which represents the state of the prototype after the persona pressed the "voice" button on the keyboard. Team Intersect-P2 found the display screen confusing to the persona but did not associate this bug with any inclusivity facets:

Intersect-P2: The numbers against each option might be confusing for [Taylor]. [Taylor] might not know how to proceed next.

Team SES-P2 agreed with Team Intersect-P2 about the bug—but used facets to reason about it. Specifically, Team SES-P2 used *Access* and *SE* to reason that the persona, Fee, would find the display screen confusing:

SES-P2: The number label might help [Fee] to guess that they have to say the number to take the action. However, it's still not clear since [Fee] might expect to see an audio icon or a keyboard prompt or even a sound (similar to Alexa listening)

Teams Intersect-P2 and SES-P2 findings satisfy the subset relation because Team Intersect-P2's judgment of "no facets" (i.e., the empty set) is a subset of SES-P2's use of *Access* and *SE*.

7. Discussion and limitations

7.1. Limitations on HCI practitioners: Missing facet types

The role of the HCI practitioners in the use of this approach is dependent the set of facet types they can use, and that set comes from the researchers who came before. The theorem is based on that set of facet types. But what if the set omits an important facet type?

Our approach depends on the completeness of the set of facet types in the underlying InclusiveMag-generated methods. Yet, neither GenderMag nor SESMag claim a complete set of facet types—instead, to support practitioner efficiency, both methods' creators selected only a subset of facet types that could have been included (Burnett et al., 2024; Burnett, Stumpf, et al., 2016). Thus, although the composition of the facet types enables complete coverage of all *values* of the facet types involved, it may not be complete in the set of facet *types*.

New facet types that arise in an intersectional population can be seen, for example, by comparing GenderMag and SESmag facets to findings in Shroff and Kam's investigation of technology adoption by low-SES women in India (Shroff & Kam, 2011). Shroff and Kam (2011) described a five-stage scale of growth towards independence among the women in their study; along these stages the women varied in such traits as their passivity vs. empoweredness, their access to resources (money, personal property), availability of emotional support, degree of literacy, and awareness of rights. Their circumstances are particular to low-SES women in a particular cultural environment, and could not have been predicted from investigating women alone or low-SES people alone. Of the 7 facet types we could derive from Shroff and Kim's descriptions, 5 to 6 were covered by the union of the GenderMag and SESMag facet types and 1–2 were not (Table 3).

When new facet types arise, however, the HCI practitioner is not without recourse. If practitioners become aware of a new facet type needed for an intersectional population, through their own practices or through new findings that emerge from intersectional researchers' empirical work, the practitioners can then add an analysis for this additional facet type to identify any new issues. Theorem 4.1 guarantees that the result is the same as re-performing a previous analysis with the added facet type. The practitioners can also add the facet type permanently to their future evaluations.

7.2. Limitations on HCI researchers: What kinds of facet types

In the realm of programming, type-based analysis allows abstracting above single values, enabling whole categories of problems to be found (e.g., multiplying a string with an integer) without having to check particular values (e.g., testing the multiplication of "hello, world" with 7). Adapting such type-level reasoning to analytical techniques in HCI can enable practical detection of problems on first principles, removing the need to check every possible value of that trait individually.

However, a limitation of InclusiveMag and its family of analytical methods is that they require the facet types to be ordinal (Section 4). This limitation is central to the approach's viability, because it is what enables HCI practitioners to check only two key facet values: the two extremes. However, this constrains the kinds of facets HCI researchers can choose: for example "age," unless constrained to be just adults's ages, would be a poor choice of facet, since software that works well for infants and the elderly does not necessarily work well for young adults. A two-ended "age" facet would thus be insufficient to discover issues faced by users of all ages. Other features like religion or native language are not even representable by a linear scale. Thus HCI researchers may need to thoughtfully decompose nuanced traits like age into subsets or more constrained facet types that do make sense as ordinal spectra.

The facet types chosen by HCI researchers can also fail to represent the underlying value space in the opposite way: they can cause HCI practitioners who eventually use the types to discover issues for combinations of extreme facet values that may not often occur in practice. However, we argue that intersectional theory calls for embracing this exact risk. During the analytical phase, HCI practitioners

Table 3. A mapping of the needs of low-SES women in India (Shroff & Kam, 2011) to facet types in GenderMag or SES-Mag.

1. At this stage, the women […] listen and absorb the information that NGOs present, but do not actively ask questions or act on this information.
SESMag: Perceived control and attitude toward authority
2. There is minimal emotional support for women; they cannot freely vent their problems to their husbands and parents-in-laws.
(no equivalent)
3. Women in passive stages … were also less at ease with technology, and hence we spent more time demonstrating the prototypes to them.
GenderMag: Computer self-efficacy
4. Women … either cannot afford items such as cellphones, or risk having their cellphones snatched by a male family member …
SESMag: Access to Reliable Technology
5. The fear of technology is commonly reported in the HCI4D literature, especially among the lowly educated, for reasons such as nervousness about damaging the device.
SESMag: Attitude toward Risk, Communication Literacy/Education/Culture
6. Women are unaware of their rights … around child rearing, education, health, family planning, sanitation and other developmental topics.
(maybe SESMag): would require at least some background about low-SES women in this geographic region to find this issue using the SESMag facet of Communication Literacy/ Education/ Culture
7. It is easy to forget the details of what was covered, and since the women are semi-literate, they cannot take notes during workshops.
SESMag: Communication Literacy/Education/Culture

Note: Two of the above facet types (computer self-efficacy and risk) are common to both methods; here we attribute them to the method most likely to have spotted the issue. E.g., if the quote emphasizes women we attribute to GenderMag and if it emphasizes SES we attribute to SESMag.

may not yet know what combinations of facet values might be found among every intersection of identities, but this method encourages them to err on the side of inclusivity.

7.3. Resource and time savings

When Nielsen introduced an HCI analytical method as part of his "discount usability" strategy (Nielsen, 1989, 2009), he was alluding to savings in monetary and time costs. As Nielsen pointed out, full-fledged empirical studies with human users can require too much time and money for some HCI researchers/practitioners to manage. Nielsen's analytical method in that paper was Heuristic Evaluation. Since that time, many other HCI analytical methods have emerged, such as GOMS, Cognitive Walkthroughs, PUM, UAN, Task-Action Grammars, syndetics, and ICS Cognitive Task Analyses (Blandford et al., 2008). As Section 2 explained, any such analytical method could be integrated into an InclusiveMag-generated method iMag($\mathcal{Dim}$). In this paper's empirical case study, the analytical method integrated into the iMag($\mathcal{Dim}$)s was the Cognitive Walkthrough.

In general, the term "discount" applies to our approach in the same way it applies to any analytical approach: it does not impose the monetary and time costs of an empirical study with human users. Empirical costs can include any or all of the following: dealing with bureaucracies that regulate studies with human participants (IRBs), human monetary incentives, travel to the study site, arranging lab space and/or equipment, preparing a tutorial and tasks, scheduling the human participants, piloting, running the study in a lab, analyzing the raw data qualitatively or quantitatively, etc. We do not further consider costs saved by omitting an empirical study, but instead focus on the costs incurred by using our approach.

The cost of our analytical approach is simply the time to do an iMag($\mathcal{Dim}$) analysis. Hilderbrand et al. has reported a GenderMag analysis to cost about 2 h (Hilderbrand et al., 2020), and Chatterjee reported about 1.5 h (Chatterjee, 2024). (Note that our approach is for *leveraging* existing iMag($\mathcal{Dim}$) methods—InclusiveMag's "Step 3" from Figure 1—not for creating new ones.) The approach can not only leverage existing iMag($\mathcal{Dim}$) methods to conduct new analyses, it can even reuse *results* of some prior use of an iMag($\mathcal{Dim}$) method to combine with newer results from using a different iMag($\mathcal{Dim}$) method, as Section 5 has already pointed out. This ability to even reuse prior results in new analyses further "discounts" the total cost.

The future holds possibilities of additional cost savings through automation. The AID tool (Chatterjee et al., 2021, 2024) has automated all or portions of GenderMag for two domains: Open-Source Project Sites and Online Education course materials. Chatterjee showed that using the latter version of this tool reduced the time required for a GenderMag analysis to less than 2 min in total (Chatterjee, 2024). The ability to automate these kinds of analytical methods is an active area of research, but the AID tool's success provides promising evidence that doing so is possible.

7.4. Complementary limitations and strengths

The analytical approach we have presented is a complement, not a replacement, for the full power that thorough empirical intersectional population research can bring. Empirical methods can capture voices that analytical methods can miss.

Still, empirical methods can also misfire due to underrepresenting intersectional voices, as Buolamwini's research (discussed earlier) revealed (Buolamwini, 2017; Buolamwini & Gebru, 2018). A strength of our approach is that it can avoid those kinds of misfires. But its greatest strength lies in providing HCI practitioners who cannot do intersectional empirical research with ways to support intersectional populations.

The empirical case study described in this paper also has limitations. Our study investigated use in practice, which was necessarily specific to the context—the particular prototype, action sequence evaluated, team dynamics, etc.—in which it was conducted. We do not regard the study's results as being generalizable beyond that context. That said, this study was conducted as a complement to a formal proof, which *is* general. The proof provides a theoretical understanding, and the study an in-practice understanding; both are needed to understand the power and utility of the approach.

7.5. The broader context

Our intersectional HCI work, although not intersectionality research per se, can still be viewed from the perspectives of three intersectionality research philosophies: Anticategorical, Intracategorical, and Intercategorical Complexity.

The *Anticategorical Complexity* philosophy rejects social categorizations entirely, advocating instead for an ethnographic, acategorical reporting style (McCall, 2005; Schlesinger et al., 2017). Dourish and Mainwaring exemplify this approach by proposing to abandon the term *user* because it tends to pigeonhole all users as belonging to a single, homogeneous group (Dourish & Mainwaring, 2012). Our work subscribes to the notion of abandoning homogeneous notions of "the user," but does not entirely reject social categorizations such as gender, race, and SES.

In contrast, the *Intracategorical Complexity* ("within-category") philosophy acknowledges social categories, but focuses on within-category variation (McCall, 2005; Schlesinger et al., 2017). An example is Woelfer and Hendry's investigation of social network websites usage by homeless youth, focusing on differences among each of the recruited participants without prior assumptions of these participants also being in categories other than "homeless youth" (Woelfer & Hendry, 2012). Our approach is consistent with the notion of intracategorical variation, but does not highlight it particularly.

The third philosophy, and the one which our work follows, is the *Intercategorical Complexity* ("between-categories") philosophy. This philosophy acknowledges different social categories that may be intersected, and illustratively reports them (e.g., studying differences and similarities in CS-related experiences of Black women, Black men and non-Black women) (McCall, 2005; Ross et al., 2020). Another example of the usage of Intercategorical Complexity philosophy in HCI is Ames et al.'s work on the differences and similarities between middle-class and working-class families in their technology choices and usage (Ames et al., 2011). Our work aims to support researchers and practitioners to reason explicitly about inclusivity issues arising in such intersections between different categories.

Note that our intersectional HCI work considers only one aspect of intersectionality. Recall that *intersectionality* is a critical social theory that has six core constructs: relationality, power, social inequality, social context, complexity, and social justice (Hill Collins, 2019), but our approach covers only one of these—relationality. As Rankin et al. (2020, 2024) have pointed out, the term *intersectionality* should be used only to describe work that covers all six aspects. They further point out that other valuable work under the *intersectional HCI* umbrella could be classified not as intersectionality per se, but rather in terms of the intersectionality aspect to which the work relates. Thus, we characterize our approach as enabling HCI practitioners to incorporate intersectional awareness early in their technology product lifecycles. Specifically, it enables practitioners to create—just in time—an intersectionally-aware inspection process to find inclusivity bugs affecting the multiple intersecting identities they intend their products to serve.

8. Conclusion

In this paper, we have presented an analytical approach to intersectional HCI. Our work aims to benefit HCI practitioners who do not have the resources to do full-fledged intersectionality research, but still would like to bring more intersectional awareness into their product design practices.

Toward supporting practitioners like these, our analytical approach draws inspiration from the programming language notion of types, to create a compositional model enabling diverse populations' types of *traits*—not their identities—to be joined and split.

Thus, our contributions are:

- An analytical method enabling HCI practitioners to reason about intersectional populations at the level of "facet types," not identities;
- A systematic compositional and decompositional model of facet types enabling diversity dimensions to be joined and split using the facet types;
- Several practical use-cases;
- A formal evaluation in the form of a formal proof;
- An empirical case study of the approach in practice, with 24 HCI researchers and practitioners.

As with other analytical methods, our approach can be used early in a product's lifecycle. The model allows the systematic decomposition and composition of diversity dimensions to facilitate flexible and customizable analysis strategies, which provably produce the same results, assuming no human error. If existing methods from the InclusiveMag family are available (e.g., GenderMag, AgeMag, SESMag), the approach is less resource-intensive than empirical approaches. Thus, it can be used as a resource-saving complement to later empirical investigations.

Our empirical results were consistent with our formal results. In an empirical study with 24 HCI participants, the model's theoretical predictions played out well. For 27 of the 28 evaluation steps, the result of the intersectionally-aware teams' analytical findings were also contained in the unions of the analytical results of the single-dimension teams. This suggests that, in practice, companies who cannot do thorough intersectional research can still use the analytical approach to improve their products' support for intersectional populations.

Ultimately, we hope this work can bring intersectional HCI to mainstream HCI practices. In earlier days of HCI, many software companies believed they could not "afford" to do HCI (Aydin et al., 2011; Donahue, 2001; Dray & Karat, 1994). However, analytical inspection methods like Heuristic Evaluation and Cognitive Walkthroughs enabled even small companies without dedicated staff to begin to affordably engage in at least some HCI practice. We believe that the approach we have presented for analytically harnessing the power of facet types can bring similar affordability to HCI practitioners' support of their users' intersecting identities.

Notes

1. We use the term *analytical methods* to refer to inspection methods (Nielsen, 1994), which HCI practitioners do *without* directly using human data. Examples include cognitive walkthroughs, expert reviews, heuristic evaluations, and applying HCI guidelines to a design.
2. Although GenderMag evaluates gender inclusivity, it does so in a gender-identity-agnostic way. For this reason, it works for all genders, not just men and women.
3. The notation $f : A \rightarrow B$ says that function f has the type $A \rightarrow B$, that is, f takes arguments of type A and returns values of type B. $Facet \times State$ denotes the set of all pairs of a facet value and a state, and 2^{Issue} denotes the powerset of *Issue*. (Note that *spot* returns a set of issues and not individual ones. So if there are N possible issues, then there are 2^N possible sets of issues.)
4. There is no technical need to use personas: Instead of iterating *spot* over two personas $persona_1$ and $persona_2$, one can just as well apply *spot* to both extreme facet values, $\max(Facet)$ and $\min(Facet)$, in each *Facet*.
5. Recall that, because these facet values are endpoints, simultaneously supporting them also supports all possible facet values and genders.
6. Of course, differences in practitioners' HCI abilities can affect the completeness of the results obtained. For example, these three methods use specialized cognitive walkthroughs, which are generally very strong at avoiding false positives, but somewhat weak at avoiding false negatives (Mahatody et al., 2010). However, human error is neither more nor less at play with this method than with any other endeavor conducted by HCI practitioners.
7. *As we explain further in Section* 6.1.4, a *bug* is a problem that a participant identified during the study, and tying it to one of the persona's facet values makes it an *inclusivity* bug.
8. Cognitive walkthroughs are subjective, and depend on the abilities and attitudes of the team doing the evaluation. That said, cognitive walkthroughs have been empirically shown to be very reliable (Mahatody et al., 2010), as we explain further in the Results subsection (Section 6.2.1).

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