FIBER BUNDLES AND INTERSECTIONAL FEMINISM

DAGAN KARP

Abstract. This note provides an introduction to, and call for action for, intersectional feminism for mathematicians. It also serves as an example of mathematical models of social structures, providing an application of geometry to social theory.

1. Gender Inequity in Mathematics

Gender inequity is historically severe and remains extant in mathematics. Although nearly half of all bachelor's[1] degrees[2] in the U.S. in mathematics are awarded to women according to the Conference Board of the Mathematical Sciences (CBMS) [4], only about 30% of the PhD's in mathematics in the U.S. are awarded to women, and further only 14% of tenured mathematics faculty are women, according to the American Mathematical Society (AMS) Annual Survey [19]. See Section 2 for a discussion of gender and gendered terms.

The underrepresentation of women in mathematics is persistent and pervasive. Comparing previous CMBS and AMS Annual Survey Data[3], we see that these critical transition points are persistent. For example, the percentage of women PhD recipients in mathematics has remained at roughly 30% for at least two decades. Hence, there is persistent gender inequity at the level of participation and representation. It is worth noting that such underrepresentation extends throughout the profession. For example, "women are underrepresented as authors of mathematics papers on the arχiv, even in comparison to the proportion of women who hold full-time positions in mathematics departments"[7]. Such patters continue to appear in peer-reviewed publications [32]. Women are also underrepresented in journal editorial boards in the mathematical sciences [39].

Gender inequity in mathematics extends well beyond representation – beyond counting bodies in the profession. The non-academic obstructions to success in mathematics for women are myriad. These include not only lack of role models and senior mentors as above, but also individual bias and structural inequities within and across institutions.

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[1]An unmarried man, according to Merriam-Webster, whereas a *maid* is therein defined as an unmarried girl or woman, especially when young or a virgin.

[2]Note the persistent misogyny in the use of B.S. and B.A. degrees. Why not all maid's degrees?

[3]AMS data is archived and updated at `http://www.ams.org/profession/data/annual-survey/annual-survey`

Individual bias (inherent, implicit, intentional, or otherwise) is one cause of gender inequity in mathematics. Moss-Racusin *et al* performed a seminal study demonstrating such bias in the sciences.

> In a randomized double-blind study ($n = 127$), science faculty from research-intensive universities rated the application materials of a student – who was randomly assigned either a male or female name – for a laboratory manager position. Faculty participants rated the male applicant as significantly more competent and hireable than the (identical) female applicant.[35]

Similarly, in another major study, over 6,500 faculty from 89 institutions were sent emails from fictitious students inquiring about research opportunities prior to applying to a doctoral program. These emails were identical in all but the name of the students; names were randomly assigned to signal gender and race. The study found "faculty were significantly more responsive to Caucasian males than to all other categories of students, collectively, particularly in higher-paying disciplines and private institutions" [33]. Harvard's Project Implicit[4] has generated thousands of citations demonstrating implicit bias along axes of gender identity (among others). For example, in one publication, Zitelny *et al* find that "Implicit measures of the gender-science stereotype are often better than explicit measures in predicting relevant outcomes"[41].

Much more important than bias held by individuals, there are systemic obstructions to success for women in mathematics. Although actions are taken by individuals, when they coalesce into clearly defined patters, it is necessary to recognize bias in the underlying institution or system in place. For example, beginning in kindergarten and increasing with age, "Teachers consistently rate girls mathematical proficiency lower than that of boys with similar achievement and learning behaviors" [10]. The evidence suggests that the U.S. education system is biased against women and privileges men from the very beginning of school. This is much more dangerous than individual bias. For an important, sophisticated, and nuanced critique of the emphasis on individual implicit bias and diversity, see [36].

In addition to a system of education biased against women, women face countless other obstructions to success in mathematics. These include, but are not limited to, macroaggressions, microaggressions, cultural exclusion, lack of role models, lack of peer support, and sexual harassment. An (problematized) attempt was made to describe some of the landscape of obstructions to equitable participation in mathematics conferences here [31]. It is imperative to listen to women and those targeted by heteronormative misogyny themselves, as Izabella Laba persuasively points out [28]. I suggest looking to the blogs of Laba[5],

[4] https://implicit.harvard.edu/implicit/

[5] `https://ilaba.wordpress.com/`

Piper H.[6], Chanda Prescod-Weinstein[7] and the Inclusion/Exclusion[8] blog of the AMS.

A word on essentialism and reduction. I have neither the lived experience nor professional training to exhaustively analyze systemic and institutional misogyny in mathematics. Rather, here I am only trying to give a glimpse of biased systems, as motivation for engaging in feminist work. Of course it would be ridiculous and essentializing to assume that any single individual, woman or otherwise, could speak on behalf of All Women, cis and trans, regardless of income, race, ethnicity, country of origin, first language, and all other aspects of identity. As Audre Lorde points out, "It is a particular academic arrogance to assume any discussion of feminist theory without examining our many differences, and without a significant input from poor women, Black and Third World women, and lesbians"[29]. Also, as women are neither the architects nor the beneficiaries of misogyny, it is necessary for all people, but especially men and those who are privileged by misogyny, to engage in the lifelong process of critical self-examination and the urgent work to dismantle systems of gender bias.

2. Language

The moduli space of genders is neither connected nor equidimensional. It is certainly not the disjoint union of two points. It is also certainly not linear with a canonical well ordering. It is not even fixed in time. So the gender binary is an incorrect model mathematically, as is a linear gender spectrum. There is instead a rich moduli space of gender identities determined by self-identification, including people who are nonbinary, agender individuals, and people with genders that are multiple or change as a function of time. The word *woman* hence of course must be used to refer to an individual who self-identifies as such at a given point it time. However historical surveys of the mathematical sciences not only assume the false gender binary, but also assign gender based on presentation. As such, there is an insufficiently analyzed disconnect between historical and current language and survey data. For an introduction to gender studies, including importantly the performative nature of gender, I refer the reader to the canonical text by Butler [8].

I am also intentional in my use of the phrase *intersectional feminism*. Because mathematicians use existential and universal quantifiers professionally, there is an unfortunate tendency by some in the field to propose an All Lives Matter approach to issues of equity in mathematics. I use intersectional feminism, as opposed to intersectionality, to highlight intersectionality as a feminist movement and framework and to highlight the brilliance and work of women, especially queer women

[6] `http://www.theliberatedmathematician.com/blog/`

[7] `https://medium.com/@chanda`

[8] `https://blogs.ams.org/inclusionexclusion/`

of color, who have lead this struggle for social justice and continue to do so in greater society and also in mathematics.

3. Feminism

In the Feminism and Visual Culture Reader, Amelia Jones writes

> Feminism is, of course, not a singular discourse to be easily defined or pinned down. Although its emergences (from the burgeoning of the suffragette movements in the late nineteenth and early twentieth centuries to the rise of women's lib in the 1960s and beyond) can be loosely mapped, its parameters and positions are under continual negotiation. This book takes feminism seriously but does not seek to patrol its boarders by, for example, labeling authors [...] 'feminist' or 'not feminist.' This kind of strategy is antithetical to the best impulses of what I take to be feminism. [25]

To give a comprehensive introduction and history of feminism is not only beyond the scope of this article, and my capabilities, but in addition I am not interested in pursuing a definitive treatment for the reasons Jones expresses above. Rather, I'll provide here a very terse introduction, intended for mathematicians who consider themselves generally unaware of the subject. There is a universe of scholarship surrounding feminist history and thought. To recommend just three texts, I suggest [1], [2], and [37].

Feminism may (reductively) be described in terms of waves of the movement. First wave feminism, from the mid-nineteenth to the early twentieth century, was centrally concerned with women's legal and political rights, such as the basic rights to vote, own property, control property, and earn and control their own income (i.e. have *separate economy*). The first wave of feminism roughly ends with the ratification of the 19th Amendment in 1920. Key figures include Elizabeth Cady Stanton and Sojourner Truth.

Second wave feminism dates roughly from the 1960s through the 1980s. Second wave feminism moved the fight from equality under the law to social equality. Second wave feminism battled sexist models of gender relations including domestic expectations for women. Key legislative victories include women's right to use birth control, have equal pay in the workplace, have educational equality, and have abortion access and reproductive freedom. Key figures include Betty Friedan and Alice Walker.

Although its roots extend back to the 1970s (or the 1670s), third wave feminism is generally described as beginning in the 1990s and is specifically *intersectional*. The gains made in first and second wave feminist movements went disproportionally to white women [2]. The Combahee River Collective played an essential role in the creation of intersectional feminism. Founded in 1974, they were a collective of

Black feminists working to "combat the manifold and simultaneous oppressions that all women of color face"[11]. In the Combahee River Collective Statement, they point out that "Black women's extremely negative relationship to the American political system (a system of white male rule) has always been determined by our membership in two oppressed racial and sexual castes"[11].

4. Intersectionality

The Combahee River Collective point to the need to be cognizant of both race and gender in general and in movements for social justice in particular. Intersectional feminism, or intersectionality, does this and much more. The term was coined by Kimberle Crenshaw, who points out

> Intersectionality was introduced in the late 1980s as a heuristic term to focus attention on the vexed dynamics of difference and the solidarities of sameness in the context of antidiscrimination and social movement politics. It exposed how single-axis thinking undermines legal thinking, disciplinary knowledge production, and struggles for social justice.[9]

This then is a first and most basic understanding of intersectionality. Single-axis frameworks are insufficient. Every individual has multiple simultaneous intersecting identities, including race, gender, ethnicity, sexuality, economic class, ability status, language, and country of origin.

This basic understanding of intersectionality is crucial and has immediate implications. Crenshaw points out that discrimination against, and even violence towards Black women (and other minoritized groups) is often seen only by carefully taking an intersectional view [12]. This has particular ramifications for instructors. For example, it may be the case that, on a given exam, there is no performance discrepancy between men and women, nor between Black students and all students, yet it may still be the case that Black women score higher on the exam than the class as a whole. Such an observation is only revealed in an intersectional analysis.

Beyond this basic understanding of intersectionality, there is a higher level, involving intersecting systems of oppression. The simple yet extremely powerful observation is that, just as aspects of identity in individuals are intersecting and inseparable, so too are the systems of oppression, bias and privilege governing our lives. Lorde points out that the U.S. is "a country where racism, sexism, and homophobia are inseparable"[29]. The Combahee River Collective not only describe themselves as being "actively committed to struggling against racial, sexual, heterosexual, and class oppression"[11], but, of basic and foundational importance in intersectional theory, they point out "the fact

that the major systems of oppression are interlocking"[11]. For example, one cannot work against sexism without also working against racism. Efforts to do so discriminate against Black women, for example, and were a major impetus for Third Wave Feminism.

How can we then understand intersectional feminism? On a basic level, we must acknowledge and honor intersecting aspects of identity. On a higher level, we must also model the intersecting nature of power structures, and the way those relate to individuals. Fiber bundles are proposed as such a model.

5. Fiber Bundles

Just as it is beyond the scope of this article to provide a comprehensive history of feminism, so too is it beyond scope to give a comprehensive description of the history and uses of fiber bundles in mathematics. Instead, I'll provide a terse introduction for mathematicians for whom this subject is new. For introductions to the subject, I recommend [5] and [34].

Fiber bundles are of basic importance in geometry and topology. Before a general definition, let's start with an example. Consider S^1 embedded as the unit circle in $\mathbb{R}^2$. Each point $p = (a, b) \in S^1$ has a tangent line at that point, T_pS^1. (Of course this is the unique line through p in direction $(-b, a)$.) Wouldn't it be nice if we could package these all together, and do so in a way such that

(1) the entire set of tangent lines had the structure of a topological space;
(2) points that are close in S^1 have tangent lines which are also close together;
(3) the set of all tangent lines has nice local structure; and
(4) the structure of the set of tangent lines gives geometric/topological insight into S^1?

The answer is yes, it would be nice and yes, we may do so. The result is the *tangent bundle* of S^1 denoted TS^1.

We now formally define the tangent bundle. Consider $S^1 \subset \mathbb{R}^2$. A vector in $\mathbb{R}^2$ is *tangent* to S^1 at p if it is the velocity vector of some smooth path through p in S^1. The set of all tangent vectors at p is denoted T_pS^1. Note that in this case all tangent vectors are parallel (to $(-b, a)$), and we recover the tangent line at p, but this construction works much more generally. Then the *tangent bundle* is defined by

$$TS^1 = \{(p, v) \in S^1 \times \mathbb{R}^2 \mid p \in S^1,\ v \in T_pS^1\}.$$

We leave it as an exercise for the reader to show that TS^1 is diffeomorphic to the infinite cylinder, $TS^1 \cong S^1 \times \mathbb{R}$. See Figure 1.

With this example in mind, let's now define a fiber bundle in general[9], following [5]. Let G be a topological group which acts effectively on a

[9]There are many equivalent definitions. A good way to get to know a geometer is to ask how they think about fiber bundles.

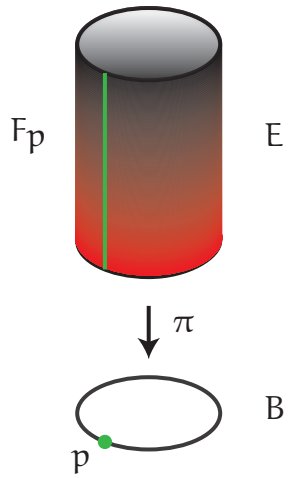

FIGURE 1. The Tangent Bundle of S^1

topological space F on the left. A surjective map $\pi : E \to B$ between topological spaces is called a *fiber bundle* with fiber F and structure group G if B has an open cover $\{U_\alpha\}$ together with fiber-preserving diffeomorphisms

$$\phi_\alpha : E|_{U_\alpha} \cong U_\alpha \times F$$

such that the *transition functions* $g_{\alpha\beta}(x) := \phi_\alpha \circ \phi_\beta^{-1}$ are continuous functions with values in G.

The tangent bundle of TS^1 is a fiber bundle with fiber $\mathbb{R}$ and structure group $GL_1(\mathbb{R}) \cong \mathbb{R}^*$, the multiplicative group if units in $\mathbb{R}$. Indeed, $\pi : TS^1 \to S^1$ is simply the projection map. Let $\epsilon > 0$ and define an open cover $\{U_1, U_2, U_3\}$ by

$$\begin{aligned} U_1 &= \{e^{i\theta} \mid -\epsilon \leqslant \theta \leqslant 2\pi/3 + \epsilon\} \\ U_2 &= \{e^{i\theta} \mid 2\pi/3 - \epsilon \leqslant \theta \leqslant 4\pi/3 + \epsilon\} \\ U_3 &= \{e^{i\theta} \mid 4\pi/3 - \epsilon \leqslant \theta \leqslant \epsilon\}. \end{aligned}$$

Then the U_i intersect pairwise and the transition functions are indeed invertible linear maps on $\mathbb{R}$. See Figure 2 below.

6. Intersectional Feminism as a Fiber Bundle

The fiber bundle model of intersectional feminism is quite simple. The base space is society, the set of people (in whatever society we are theorizing). An open cover consists of aspects of identity and their refinements. This open cover of the base space reveals the basic and first observation of intersectionality, that people have intersecting and inseparable aspects of identity, such as race, gender, and sexuality: we each occupy the intersection of multiple sets. But above each of us

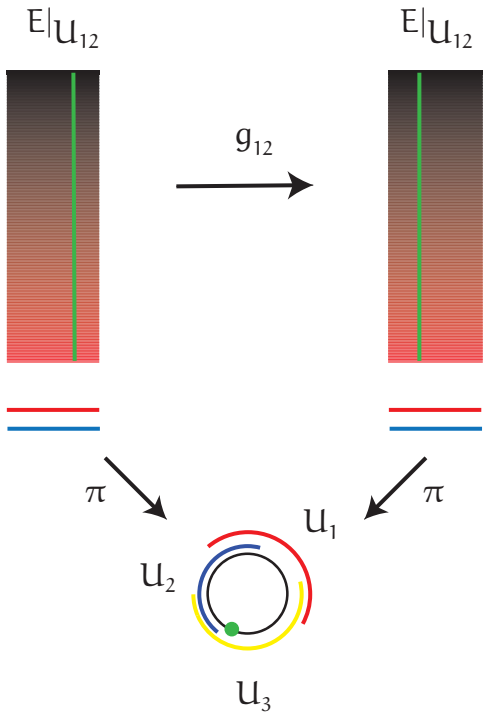

FIGURE 2. Transition Functions and Local Trivializations in TS^1

lie the preimages of these open sets; above us lies a complex web of social structures and systems of oppression, such as racism, misogyny, homophobia and transphobia. These preimages above, the local trivializations, reveal the higher structure of intersectionality, that systems of oppression are also intersecting and cannot be separated. The transition functions preserve the structure of the bundle, illuminating the intersectional premise that the social fiber above each individual has the same structure and is preserved as we operate within biased systems.

And what is the fiber? Building off bell hooks [24], the social fiber in the U.S. is ableist cis-heteronormative white-supremacist capitalist patriarchy. Just as points in the base space of a fiber bundle all have isomorphic fibers above, so too do all people in society live under systems of oppression. (Of course the impact of these systems differs across people; that's somehow the point.) Just as transition functions preserve the structure of the fiber, so too in our interactions between people are we living under the influence of our biased social fiber. This is consistent with the hegemonic nature of oppression.

7. PRAXIS

As the saying goes, in theory there is theory and practice, but in practice there is only practice.[10] What practices work toward a society that is no longer accurately modeled as a bundle with ableist cisheteronormative white-supremacist capitalist patriarchy as fibers? In particular, how may we work against oppression in and through mathematics? Fortunately there is a wealth of scholarship and lessons learned from past practice of which we mathematicians may avail ourselves.

Within mathematics education, intersectional feminism plays an important role in critical pedagogy theory and practice. In her groundbreaking text Teaching to Transgress, bell hooks brings an intersectional feminist lense (and much more) to critical education theory [23]. Critical education theory goes back to Paulo Freire; it challenges the banking model of education and posits education as a liberatory practice [14, 17]. Through engaging with Teaching to Transgress, one may adopt intersectional feminist practices in education. Marilyn Frankenstein brings critical pedagogy specifically into mathematics education [16], and this work is furthered by F. A. Tutak [40].

This opens the door to the world of (mathematics) education informed by and consistent with intersectional feminist practice, including but certainly not limited to anti-oppressive education [27], social justice oriented (mathematics) education [21, 26], critical race theory in mathematics [15, 30], and ethnomathematics [13].

To highlight in more detail the work of a few individuals, Estela Bensimon has research-based suggestions for individual and institutional self-analysis and improvement. Following her Diversity Scorecard, individual instructors may analyze their grades by race and gender [3]. Focusing on an intersectional lense, we should pay attention to these data not only separately, but also in the intersection, lest bias against low-income students with disabilities, or women of color, go unreported. Similarly we should take an intersectional feminist lense in all our classroom practices, including not only our gradebooks, but our co-construction of classroom dynamics, our journey toward equity centered pedagogy, our efforts toward rehumanization, and universal design.

At the institutional level, we must also use intersectional analyses. For example, Bensimon's Diversity Scorecard is not only a tool designed for instructors, but rather it is a method of institutional analysis [3]. We should push our institutions to perform such institutional intersectional analysis, for example as overseen by the University of Southern California's Center for Urban Education, in the case of the Diversity Scorecard. Similarly we may turn our attention to hiring committees,

[10]To quote Benjamin Brewster in the Yale Literary Magazine in 1882, "What does his lucid explanation amount to but this, that in theory there is no difference between theory and practice, while in practice there is?[6, p.202]"

tenure and promotion committees, departmental and institutional leadership. Such structural changes have potential for significant impact.

Turning to another scholar, Nicole Joseph has a specifically intersectional lense in mathematics education research. She explores the intersectional experiences of Black women [38]. And she analyzes ways to disrupt practices that minoritize Black women in mathematics using key frameworks from critical race theory [22]. Mathematicians interested in finding research-based practices working toward intersectional feminism in mathematics education need only look to her oeuvre.

Finally, Rochelle Gutierrez pushes past equity toward rehumanization [18], and beyond rehumanization to the world of Mathematx [20]. Her work is very broad, and includes intersectionality foundationally. Mathematx is conceptualization of the practice of mathematics which incorporates ideas from many sources including postcolonial theory and indigenous knowledge. Just as I generally don't recommend scheme theory to first-year undergraduate students, I don't recommend Mathematx for people unfamiliar with ethnomathematics, critical race theory, gender studies, and some grounding in mathematics education. But it is worthy of the prerequisite study; it is powerful, beautiful, important and imperative.

The presence of systems in mathematics which bias some and privilege others dispels the myth of the meritocracy. We must continuously work to dismantle systems of oppression, to change the fiber of our profession, for the benefit of the mathematics community and beyond.

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