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U.S. DISTRICT COURT
N.D. OF ALABAMA

**UNITED STATES DISTRICT COURT**
**FOR THE NORTHERN DISTRICT OF ALABAMA**

EVAN MILLIGAN, et al.,

*Plaintiffs*,

v.

JOHN H. MERRILL, et al.,

*Defendants*.

Civil Case No. 2:21-CV-01530-AMM

**DECLARATION OF MOON DUCHIN, PH.D.**

I, Moon Duchin, declare:

1. My name is Moon Duchin. I am over 18 years of age and have personal knowledge of the facts set forth in this Declaration.

2. I hold a Ph.D. and an M.S in Mathematics from the University of Chicago as well as an A.B. in Mathematics and Women's Studies from Harvard University.

3. I am a Professor of Mathematics and a Senior Fellow in the Jonathan M. Tisch College of Civic Life at Tufts University. I hold an affiliation as Collaborating Faculty in the American Studies track within the Department of Race, Colonialism, and Diaspora Studies.

4. A copy of my expert report and exhibits in support, including a current copy of my full CV, are attached as Exhibit 1 to this declaration.

5. All of the quantitative work described in my report was performed by myself with the support of research assistants working under my direct supervision.

6. I am compensated at the rate of $300 per hour. My compensation for my work on this case is not dependent on the substance of my opinions or the outcome of the case.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge.

Executed on December 10, 2021 in Medford, Massachusetts.

Moon Duchin

# Exhibit 1

# Presentation of Alternative Congressional Districting Plans for Alabama

Moon Duchin
Professor of Mathematics, Tufts University
Collaborating Faculty in Race, Colonialism, and Diaspora Studies
Senior Fellow, Tisch College of Civic Life

December 10, 2021

## 1 Background, qualifications, and materials consulted

I am a Professor of Mathematics and a Senior Fellow in the Jonathan M. Tisch College of Civic Life at Tufts University. I hold an affiliation as Collaborating Faculty in Department of Race, Colonialism, and Diaspora Studies (American Studies track). I hold a Ph.D. and an M.S in Mathematics from the University of Chicago as well as an A.B. in Mathematics and Women's Studies from Harvard University.

My general research areas are geometry, topology, dynamics, and applications of mathematics and computing to the study of elections, voting, and civil rights. My redistricting-related work has been published in venues such as the Election Law Journal, Political Analysis, Foundations of Data Science, the Notices of the American Mathematical Society, Statistics and Public Policy, the Virginia Policy Review, the Harvard Data Science Review, Foundations of Responsible Computing, and the Yale Law Journal Forum. My research has had continuous grant support from the National Science Foundation since 2009, including a CAREER grant from 2013–2018 and a Convergence Accelerator grant from 2019–2021 entitled "Network Science of Census Data." I am currently on the editorial board of the journals Advances in Mathematics and the Harvard Data Science Review. I was elected a Fellow of the American Mathematical Society in 2017 and was named a Radcliffe Fellow and a Guggenheim Fellow in 2018.

### Materials

I consulted a range of materials while preparing this report:

- Data products published by the Census Bureau, especially the PL94-171 Decennial Census release, the 2015-19 American Community Survey, and the ACS Special Tabulation from the same 5-year period. The Census Places dataset was used to extract block assignments to cities and towns. TIGER/Line shapefiles were used to pair demographics with geography.
- Block equivalency files defining the State's new enacted districts from `www.sos.alabama.gov/alabama-votes/state-district-maps`.
- The Alabama Legislature's *Reapportionment Committee Redistricting Guidelines* [1], as well as the other articles cited in the bibliography below.

## 2 Introduction

On November 3, 2021, the Alabama Legislature enacted four districting plans: maps of 7 U.S. Congressional districts, 35 state Senate districts, 105 state House districts, and 8 state Board of Education districts. They were signed into law by Governor Kay Ivey the next day. This report presents alternative plans for Alabama Congressional districts and contrasts them with the enacted plan. I was asked to draw plans that establish that it is possible to create two majority-Black districts in a map that maintains population balance, reasonable compactness, respect for political boundaries, and other traditional districting principles. In particular, I was instructed to emphasize the Polsby-Popper (isoperimetric) definition of compactness.

I will be comparing the following plans: the enacted plan HB-1 and a set of alternative plans that I have drawn, labeled Plan A, Plan B, Plan C, and Plan D. They are shown in Figures 1-2.

The focus of this report is to establish that the first Gingles factor, known as "Gingles 1," is met:

> *First, the minority group must be able to demonstrate that it is sufficiently large and geographically compact to constitute a majority in a single-member district.*[1]

Together with Gingles 2 and 3, the factors establishing racially polarized voting, these stand as the threshold conditions for advancing litigation under the Voting Rights Act.

Alabama's largest minority group is Black, with 1,364,736 out of 5,024,279 residents—27.16% of the total population—identifying as Black, possibly in combination with other races, of any ethnicity, on their Census forms. This group is therefore large enough to constitute majorities of three out of seven congressional districts.[2] However, the second half of the Gingles 1 condition requires that we take the human geography into account, considering whether the group's residential location is sufficiently geographically compact to achieve majority-minority districts. The constraints of geography make it impossible to create three, but I will show that **it is readily possible to create two majority-Black Congressional districts in Alabama today**.

Furthermore, these two majority-Black districts can be drawn without sacrificing traditional districting principles like population balance (§3.1), contiguity (§3.2), respect for political subdivisions like counties, cities, and towns (§3.3), or the compactness of the districts (§3.4), and with heightened respect for communities of interest (§3.5).

[1] *Thornburg v. Gingles*, 478 U.S. 30 (1986)

[2] Since each district will contain 1/7 (or about 14.3%) of the population, it follows that 7.2% of the population is enough to constitute the majority in a district. Alabama's Black population is more than three-and-a-half times this numerous. Thus, in terms of numbers alone, three districts could have Black population majorities by a comfortable margin.

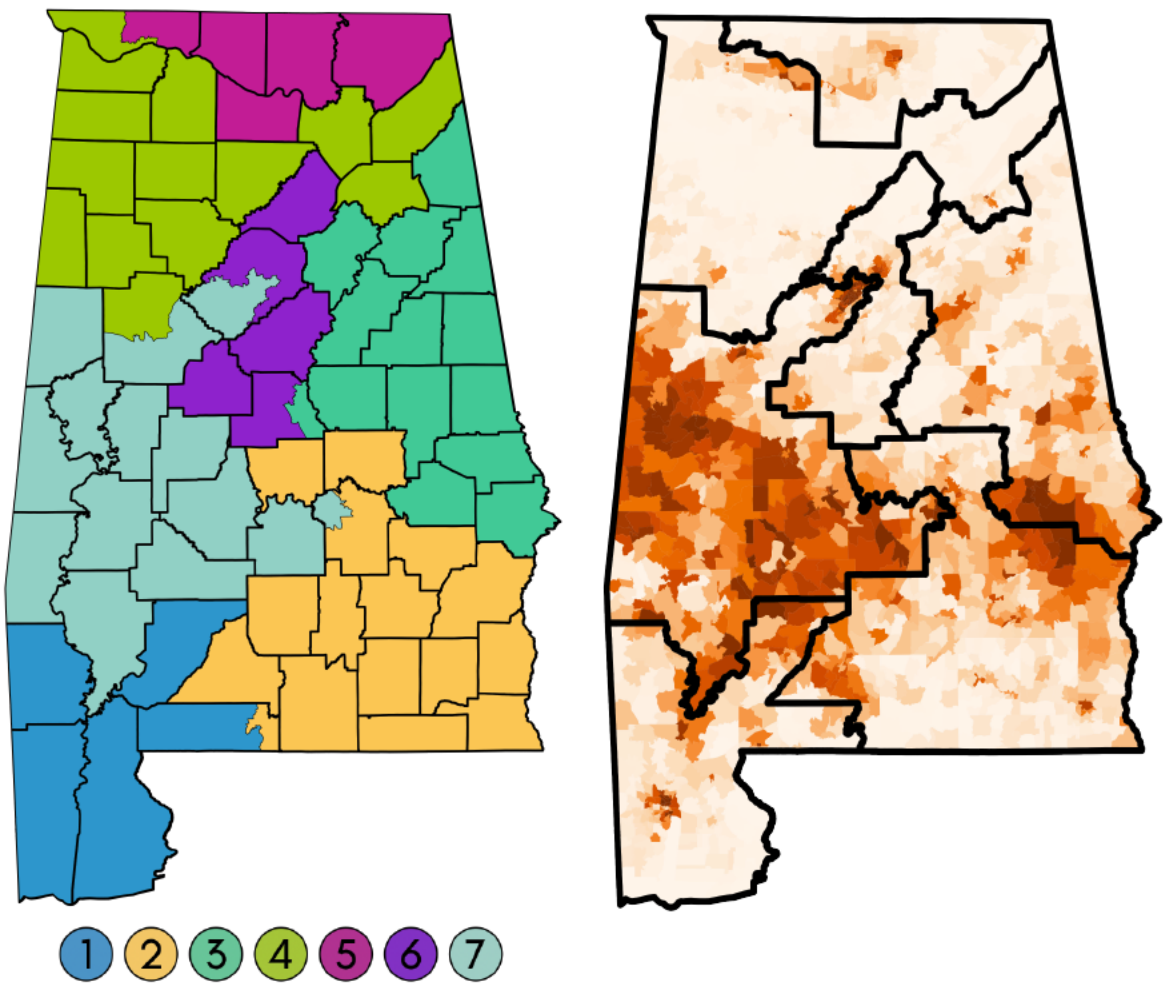


Figure 1: The State's plan HB-1 is shown (left) next to a demographic map (right). Darker shading indicates precincts with a higher share of BVAP, or Black voting age population. The State's plan packs Black population into District 7 at an elevated level of over 55% BVAP, then cracks Black population in Mobile, Montgomery, and the rural Black Belt across Districts 1, 2, and 3, so that none of them has more than about 30% BVAP.

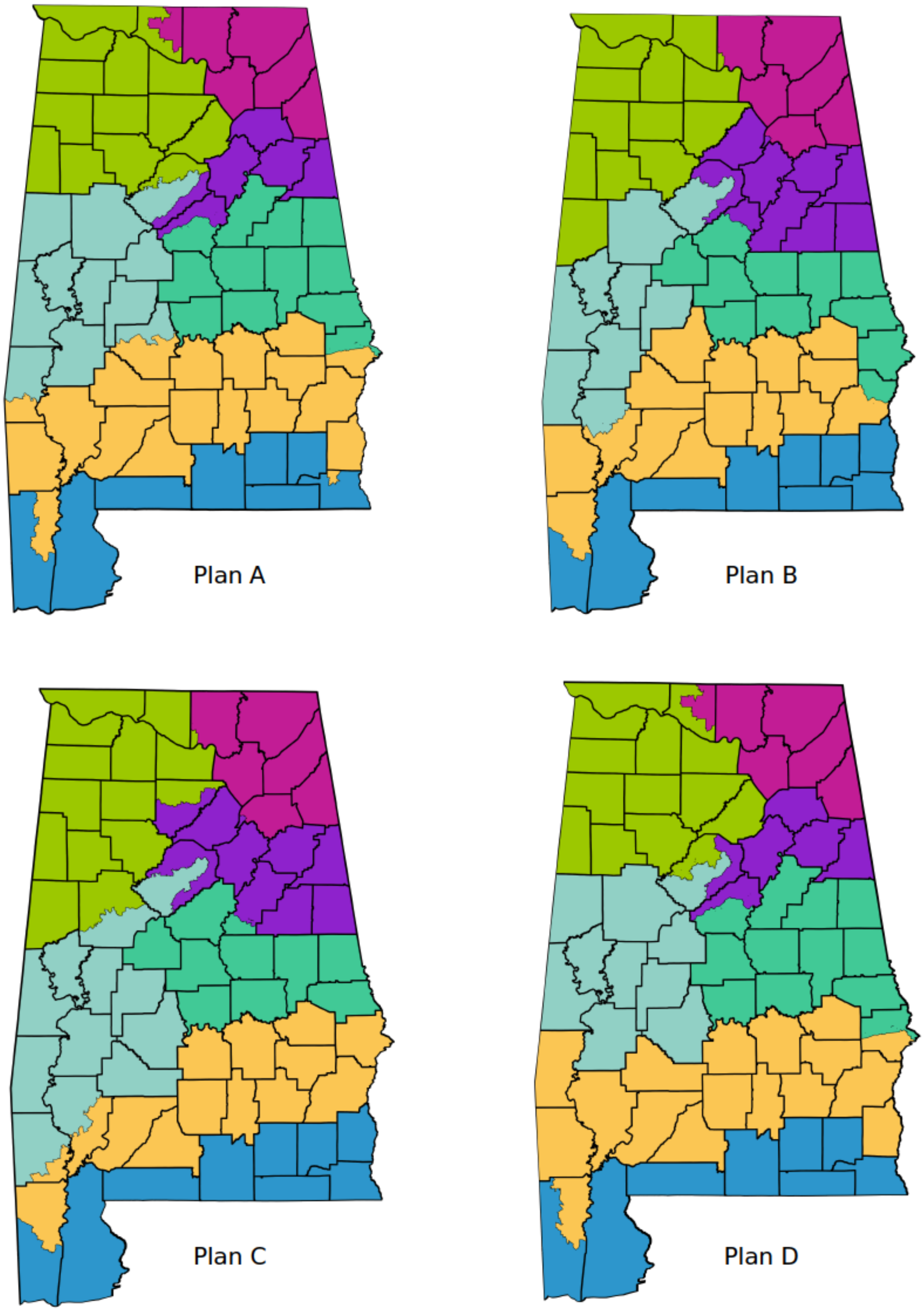


Figure 2: The four alternative plans presented in this report.

# 3 Traditional districting principles

I will begin by surveying the criteria discussed in the Alabama Legislature's *Reapportionment Committee Redistricting Guidelines* (henceforth, "the Guidelines") [1].

## 3.1 Population balance

The standard interpretation of *One Person, One Vote* for Congressional districts is that districts should be balanced to as near mathematical equality of population as possible, using total population from the Decennial Census. As the Guidelines put it, "*Congressional districts shall have minimal population deviation.*" The State's plan and all four alternative plans have very tight population balance, with each district within one-person deviation from the rounded ideal population of 717,754.

## 3.2 Contiguity

A district formed from census blocks can be called *contiguous* if it is possible to transit from any part of the district to any other part through a sequence of blocks that share boundary segments of positive length. As is traditional in Alabama (and affirmed in Section II.j.ii of the Guidelines), contiguity through water is accepted. The State's plan and the four alternative plans all satisfy contiguity.

## 3.3 Respect for political subdivisions

The Guidelines call for districting plans to "*respect communities of interest, neighborhoods, and political subdivisions*"; in redistricting terms, respect for political subdivisions can be interpreted as attempting to keep intact as many localities (counties, cities, and towns) as possible. In order to make seven finely population-tuned districts, it is necessary to split at least six of Alabama's 67 counties into two pieces, or to split some counties into more than two pieces. All of the plans under consideration—the State's plan and the four alternative maps—split nine counties or fewer, giving them high marks for respecting these major political subdivisions. Plan D in fact splits only five counties, with the largest county (Jefferson) touching three districts. On the municipal level, Alabama has 172 cities and 290 towns, according to the 2020 Census. All of the alternative plans are comparable to the State's plan on locality splits, with Plan B splitting fewer localities than HB-1.

**Number of localities split, by type**

| | localities (out of 529) | counties (out of 67) | municipalities (out of 462) | majority-Black cities (out of 32) |
|---|---|---|---|---|
| HB-1 | 42 | 6 | 36 | Adamsville, Bessemer, Birmingham, Montgomery, Tarrant (5) |
| Plan A | 48 | 8 | 40 | Adamsville, Bessemer, Birmingham, Pritchard (4) |
| Plan B | 39 | 7 | 32 | Bessemer, Birmingham (2) |
| Plan C | 51 | 9 | 42 | Adamsville, Bessemer, Birmingham (3) |
| Plan D | 49 | 5 | 44 | Adamsville, Bessemer, Birmingham, Pleasant Grove, Tarrant (5) |

Table 1: Comparing the plans' conformance to political boundaries. Municipalities are defined as cities and towns, and localities includes these as well as counties.

### 3.4 Compactness

The two compactness metrics most commonly appearing in redistricting are the *Polsby-Popper score* and the *Reock score*. Polsby-Popper is the name given in this setting to a metric from ancient mathematics: the isoperimetric ratio comparing a region's area to its perimeter via the formula $4\pi A/P^2$. Higher scores are considered more compact, with circles uniquely achieving the optimum score of 1. Political scientist Ernest Reock created a different score based on the premise that circles were ideal: it is computed as the ratio of a region's area to that of its circumcircle, where the circumcircle is defined as the smallest circle in which the region can be circumscribed. Polsby-Popper is thought to be relevant as a measure of how erratically the geographical boundaries divide the districts, but this sometimes penalizes districts for natural features like coastlines of bays and rivers. Reock has a much weaker justification, since the primacy of circles is the goal rather than the consequence of the definition.[3]

These scores depend on the planar contours of a district and have been criticized as being too dependent on map projections or on cartographic resolution [2, 3]. Besides having the weakest relevance to redistricting, the Reock score is also technically flawed, subject to large distortions among different equally reasonable methods of computation. Recently, some mathematicians have argued for using discrete compactness scores, taking into account the units of Census geography from which the district is built. The most commonly cited discrete score for districts is the *cut edges* score, which counts how many adjacent pairs of geographical units receive different district assignments. In other words, cut edges measures the "scissors complexity" of the districting plan: how much work would have to be done to separate the districts from each other? Plans with a very intricate boundary would require many separations. Relative to the contour-based scores, this better controls for factors like coastline and other natural boundaries, and focuses on the units actually available to redistricters rather than treating districts like free-form Rorschach blots.

**Compactness**

| | block cut edges (lower is better) | average Polsby-Popper (higher is better) | average Reock (higher is better) |
|---|---|---|---|
| HB-1 | 3230 | 0.222 | 0.427 |
| Plan A | 3417 | 0.256 | 0.378 |
| Plan B | 3127 | 0.282 | 0.365 |
| Plan C | 3774 | 0.255 | 0.338 |
| Plan D | 3540 | 0.249 | 0.399 |

Table 2: Comparing compactness scores via one discrete and two contour-based metrics. Plan B is the most compact by cut edges. All four alternative plans are superior to the State's plan on the Polsby-Popper metric and have very reasonable Reock scores, especially Plan D.

### 3.5 Additional principles

- **Communities of interest.** The Guidelines describe communities of interest in terms that are congruent with the usage across many states: "*A community of interest is defined as an area with recognized similarities of interests, including but not limited to ethnic, racial, economic, tribal, social, geographic, or historical identities.*"

  In Alabama, there was no sustained effort by any state authority to formally collect community of interest (COI) maps, to my knowledge. Without this, it is difficult to produce a suitable metric based on public testimony or submissions.

[3]Reock took the idealization of the circle for granted: "The most compact plane figure is the circle, for here the maximum area is enclosed within a given perimeter. The circle, therefore, can be used as the ideal of compactness..." [4]. No further justification is given for why non-circular shapes are plausible indicators of gerrymandering.

However, it is possible to identify several clear examples of communities of interest of particular salience to Black Alabamians. The "Black Belt" of 18 mostly rural counties will be discussed below in §4.2.2.

- **Cores of prior districts.** The State's plan HB-1 bears a close resemblance to the plan from the prior Census cycle, which was engineered to have one district with a Black supermajority, while the other six do not approach one-third Black population. Therefore it should be expected that plans designed to address Voting Rights Act concerns would disrupt the structure of the prior plans, which can be confirmed in the alternative plans presented here.

# 4 Racial demographics

## 4.1 Demographics

Over 1.3 million Alabamians, or 1,364,736 to be precise, identified as Black or African-American on the 2020 Decennial Census.[4] Over a million of these, namely 1,014,372, are of voting age. Black residents constitute 27.16% of total population, 25.9% of voting-age population, and 26.3% of citizen voting-age population in the state.[5] But in the last Census cycle as in the State's new proposed plan, just one district out of seven had close to a Black majority—that one district constitutes just under 14.3% of the seats, while two majority-Black districts can readily be produced in alternative districting plans.

**VAP**

**BVAP Share by District**

| CD | HB-1 | Plan A | Plan B | Plan C | Plan D |
|---|---|---|---|---|---|
| 1 | 25.61% | 14.50% | 15.73% | 15.73% | 15.36% |
| 2 | 30.12% | 51.37% | 51.06% | 50.06% | 50.05% |
| 3 | 24.99% | 23.96% | 22.28% | 19.64% | 23.96% |
| 4 | 7.70% | 8.30% | 10.86% | 11.03% | 8.58% |
| 5 | 18.06% | 16.02% | 15.66% | 15.66% | 16.02% |
| 6 | 18.93% | 15.44% | 15.32% | 15.51% | 15.37% |
| 7 | 55.26% | 51.50% | 50.24% | 53.50% | 51.73% |

**WVAP Share by District**

| CD | HB-1 | Plan A | Plan B | Plan C | Plan D |
|---|---|---|---|---|---|
| 1 | 66.00% | 76.25% | 75.20% | 75.20% | 75.47% |
| 2 | 62.03% | 42.33% | 42.60% | 43.14% | 43.56% |
| 3 | 67.74% | 67.78% | 68.47% | 70.99% | 67.78% |
| 4 | 82.41% | 82.98% | 80.12% | 79.98% | 82.63% |
| 5 | 70.89% | 71.62% | 72.56% | 72.56% | 71.62% |
| 6 | 71.16% | 75.39% | 76.73% | 76.49% | 75.58% |
| 7 | 38.60% | 42.08% | 42.71% | 40.04% | 41.82% |

**CVAP**

**BCVAP Share by District**

| CD | HB-1 | Plan A | Plan B | Plan C | Plan D |
|---|---|---|---|---|---|
| 1 | 25.77% | 14.54% | 15.77% | 15.77% | 15.41% |
| 2 | 30.49% | 52.05% | 51.75% | 50.78% | 50.71% |
| 3 | 25.21% | 24.26% | 22.63% | 19.97% | 24.26% |
| 4 | 7.70% | 8.35% | 10.91% | 11.10% | 8.62% |
| 5 | 18.23% | 16.25% | 15.84% | 15.84% | 16.25% |
| 6 | 19.33% | 15.62% | 15.48% | 15.66% | 15.53% |
| 7 | 56.34% | 52.40% | 51.28% | 54.51% | 52.64% |

**WCVAP Share by District**

| CD | HB-1 | Plan A | Plan B | Plan C | Plan D |
|---|---|---|---|---|---|
| 1 | 65.17% | 75.19% | 74.13% | 74.13% | 74.40% |
| 2 | 61.43% | 41.89% | 42.19% | 42.65% | 43.14% |
| 3 | 67.49% | 67.61% | 68.37% | 71.04% | 67.61% |
| 4 | 82.50% | 82.62% | 79.88% | 79.78% | 82.30% |
| 5 | 70.42% | 71.24% | 72.28% | 72.28% | 71.24% |
| 6 | 71.23% | 75.83% | 76.63% | 76.35% | 76.01% |
| 7 | 38.02% | 41.51% | 42.24% | 39.53% | 41.22% |

Table 3: Demographics broken out as a comparison of Black and White population.

[4] Here and throughout, we use the so-called "Any Part Black" definition, which counts people who self-identified as Black on the Census form, possibly in combination with other races, whether Hispanic or not, for total population and voting-age population. Abbreviations such as BVAP refer to this construction. Citizen voting-age population is derived from the American Community Survey (ACS) in combination with the Decennial Census. The racial group constructions are fully defined in the supplemental material.

[5] Black citizen voting-age population is derived from the 5-year ACS, 2015–2019. The supplemental material contains an explanation of how BCVAP and WCVAP are constructed.

| | CD | WVAP | BVAP | HVAP | WCVAP | BCVAP | HCVAP |
|---|---|---|---|---|---|---|---|
| HB-1 | 1 | 66.00% | 25.61% | 3.23% | 65.17% | 25.77% | 2.45% |
| | 2 | 62.03% | 30.12% | 3.57% | 61.43% | 30.49% | 2.55% |
| | 3 | 67.74% | 24.99% | 3.07% | 67.49% | 25.21% | 2.29% |
| | 4 | 82.41% | 7.70% | 5.66% | 82.50% | 7.70% | 2.84% |
| | 5 | 70.89% | 18.06% | 5.28% | 70.42% | 18.23% | 3.31% |
| | 6 | 71.16% | 18.93% | 5.38% | 71.23% | 19.33% | 2.81% |
| | 7 | 38.60% | 55.26% | 3.65% | 38.02% | 56.34% | 2.05% |

| | CD | WVAP | BVAP | HVAP | WCVAP | BCVAP | HCVAP |
|---|---|---|---|---|---|---|---|
| Plan A | 1 | 76.25% | 14.50% | 4.00% | 75.19% | 14.54% | 3.07% |
| | 2 | 42.33% | 51.37% | 2.68% | 41.89% | 52.05% | 1.77% |
| | 3 | 67.78% | 23.96% | 3.98% | 67.61% | 24.26% | 2.62% |
| | 4 | 82.98% | 8.30% | 4.58% | 82.62% | 8.35% | 2.58% |
| | 5 | 71.62% | 16.02% | 6.50% | 71.24% | 16.25% | 3.67% |
| | 6 | 75.39% | 15.44% | 3.91% | 75.83% | 15.62% | 2.26% |
| | 7 | 42.08% | 51.50% | 4.18% | 41.51% | 52.40% | 2.32% |

| | CD | WVAP | BVAP | HVAP | WCVAP | BCVAP | HCVAP |
|---|---|---|---|---|---|---|---|
| Plan B | 1 | 75.20% | 15.73% | 3.99% | 74.13% | 15.77% | 3.06% |
| | 2 | 42.60% | 51.06% | 2.60% | 42.19% | 51.75% | 1.71% |
| | 3 | 68.47% | 22.28% | 4.59% | 68.37% | 22.63% | 2.92% |
| | 4 | 80.12% | 10.86% | 4.68% | 79.88% | 10.91% | 2.70% |
| | 5 | 72.56% | 15.66% | 6.23% | 72.28% | 15.84% | 3.40% |
| | 6 | 76.73% | 15.32% | 3.46% | 76.63% | 15.48% | 2.11% |
| | 7 | 42.71% | 50.24% | 4.29% | 42.24% | 51.28% | 2.41% |

| | CD | WVAP | BVAP | HVAP | WCVAP | BCVAP | HCVAP |
|---|---|---|---|---|---|---|---|
| Plan C | 1 | 75.20% | 15.73% | 3.99% | 74.13% | 15.77% | 3.06% |
| | 2 | 43.14% | 50.06% | 2.93% | 42.65% | 50.78% | 1.95% |
| | 3 | 70.99% | 19.64% | 4.46% | 71.04% | 19.97% | 2.82% |
| | 4 | 79.98% | 11.03% | 4.70% | 79.78% | 11.10% | 2.69% |
| | 5 | 72.56% | 15.66% | 6.23% | 72.28% | 15.84% | 3.40% |
| | 6 | 76.49% | 15.51% | 3.51% | 76.35% | 15.66% | 2.13% |
| | 7 | 40.04% | 53.50% | 4.01% | 39.53% | 54.51% | 2.26% |

| | CD | WVAP | BVAP | HVAP | WCVAP | BCVAP | HCVAP |
|---|---|---|---|---|---|---|---|
| Plan D | 1 | 75.47% | 15.36% | 4.01% | 74.40% | 15.41% | 3.07% |
| | 2 | 43.56% | 50.05% | 2.68% | 43.14% | 50.71% | 1.79% |
| | 3 | 67.78% | 23.96% | 3.98% | 67.61% | 24.26% | 2.62% |
| | 4 | 82.63% | 8.58% | 4.66% | 82.30% | 8.62% | 2.61% |
| | 5 | 71.62% | 16.02% | 6.50% | 71.24% | 16.25% | 3.67% |
| | 6 | 75.58% | 15.37% | 3.93% | 76.01% | 15.53% | 2.25% |
| | 7 | 41.82% | 51.73% | 4.08% | 41.22% | 52.64% | 2.30% |

Table 4: Demographics by district in the State's plan HB-1 and the alternative plans.

By contrast, the non-Hispanic White population share in Alabama is 63.12% and the corresponding shares of voting-age population and citizen voting-age population are 65.47% and 65.07%, respectively. By any of these measures, proportional representation for White voters would be between 4.4 and 4.6 of Alabama's 7 seats in the U.S. House. The State's map HB-1 orchestrates a non-Hispanic White VAP share of at least 60% in all districts besides CD-7—that is, in 6 out of 7 Congressional districts.

## 4.2 Centers of Black population

### 4.2.1 Urban

The four largest cities in Alabama today are Huntsville (population 215,006), Birmingham (population 200,733), Montgomery (population 200,603), and Mobile (population 187,041). Together, they have over 400,000 Black residents, comprising roughly 1/3 of the Black population in the state. Of these cities, Birmingham, Montgomery, and Mobile are majority-Black, with population shares of 69.9%, 60.8%, and 51.5%, respectively, making them two among Alabama's 52 majority-Black cities.

Of those four largest cities, the State's plan HB-1 only includes parts of Birmingham and parts of Montgomery in a majority-Black district. In particular, this means that the hundreds of thousands of Black voters in Montgomery and Mobile are located in districts in which Black population share falls short of one-third.

All four alternative plans retain most of Birmingham in a majority-Black district, but by adding a second majority district the alternative plans are able to include all of Montgomery and most of Mobile as well.

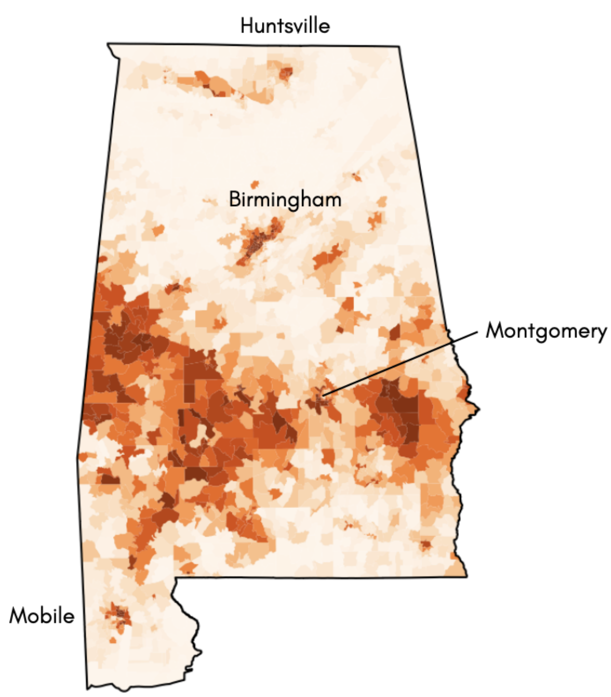


Figure 3: Black voting-age population share is shown by shading at the precinct level. The major cities have visible concentrations of Black population, and the Black Belt rural counties are clearly visible running East-West across the state.

### 4.2.2 Rural: Alabama's Black Belt

Alabama also has a significant Black population in rural counties, especially in the 18 "Black Belt" counties of Barbour, Bullock, Butler, Choctaw, Crenshaw, Dallas, Greene, Hale, Lowndes, Macon, Marengo, Montgomery, Perry, Pickens, Pike, Russell, Sumter, and Wilcox. These counties have a long shared history from plantation slavery to sharecropping to Jim Crow and up to the present—these constitute very clear communities of interest by the Guidelines definition. (Recalling from above, that definition holds that "*A community of interest is defined as an area with recognized similarities of interests, including but not limited to ethnic, racial, economic, tribal, social, geographic, or historical identities.*")

The Black Belt includes 8 of the 10 least populous counties in the state, each with under 13,000 residents. Together, the Black Belt region has over 300,000 Black residents.

In the State's plan, eight of these are partially or fully excluded from majority-Black districts: Barbour, Bullock, Butler, Crenshaw, Macon, Pike, and Russell are excluded from CD-7 while Montgomery County is split.

Each of the 18 Black Belt counties is contained in majority-Black districts in at least some of the alternative plans presented here: Plan A and Plan D include all but part of Russell County, Plan B includes all but Russell and part of Barbour County, and Plan C includes the entirety of the Black Belt. Forming a district that reaches south into Mobile County and eastward across the Black Belt is natural for a mapmaker following traditional principles. In fact, the State's own recently enacted State Board of Education map, which has two majority-Black districts out of eight, does just this in a manner similar to my illustrative Congressional plans.

# 5 Conclusion

I have presented four alternative maps that all secure population majorities for Black Alabamians in two districts, rather than just one district, out of seven.

- The State's map and all four alternative plans have districts balanced to within ±1 person from rounded ideal size. All four plans are contiguous, and all split five to nine counties, at or close to the theoretical minimum level of splitting.
- All four alternative plans have strong compactness scores; in fact, all four are significantly superior to the State's plan in the most common compactness metric, the average Polsby-Popper score.
- The State's plan splits Montgomery County and Montgomery City, even though Montgomery County is less than one-third the size of a Congressional district. All four alternative plans hold the city and county whole.
- Proportionality for the White non-Hispanic population in Alabama would amount to roughly 4.5 out of 7 seats in Congress, but the State's map would lock in fully 6 out of 7 seats for White-preferred candidates—a massively super-proportional showing.
- All four alternative plans place thousands of Black voters in the population centers of Montgomery and Mobile, as well as voters across the rural Black Belt, in majority-Black districts. Seven Black Belt counties are wholly excluded from the sole majority-Black district, and another is split, in the State's plan. Relative to HB-1, each one of the alternative plans allows over 300,000 additional Black Alabamians—including plaintiffs Shalela Dowdy (Mobile), Evan Milligan (Montgomery), and Khadidah Stone (Montgomery)—to live in majority-Black districts.

## References


[1] Alabama Legislative Reapportionment Committee Redistricting Guidelines, dated May 5, 2021. *Available at* www.legislature.state.al.us.

[2] Assaf Bar-Natan, Elle Najt, and Zachary Schutzmann, *The gerrymandering jumble: Map projections permute districts' compactness scores*. Cartography and Geographic Information Science, Volume 47, Issue 4, 2020, 321–335.

[3] Richard Barnes and Justin Solomon, *Gerrymandering and Compactness: Implementation Flexibility and Abuse.* Political Analysis, Volume 29, Issue 4, October 2021, 448–466.

[4] Ernest C. Reock, Jr., *A Note: Measuring Compactness as a Requirement of Legislative Apportionment.* Midwest Journal of Political Science, Vol. 5, No. 1 (Feb., 1961), 70–74.

# A Supplemental information

Definition of Black by Census Codes (within **total population**)

```
Black or African American alone P0010004
White; Black or African American P0010011
Black or African American; American Indian and Alaska Native P0010016
Black or African American; Asian P0010017
Black or African American; Native Hawaiian and Other Pacific Islander P0010018
Black or African American; Some Other Race P0010019
White; Black or African American; American Indian and Alaska Native P0010027
White; Black or African American; Asian P0010028
White; Black or African American; Native Hawaiian and Other Pacific Islander P0010029
White; Black or African American; Some Other Race P0010030
Black or African American; American Indian and Alaska Native; Asian P0010037
Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander P0010038
Black or African American; American Indian and Alaska Native; Some Other Race P0010039
Black or African American; Asian; Native Hawaiian and Other Pacific Islander P0010040
Black or African American; Asian; Some Other Race P0010041
Black or African American; Native Hawaiian and Other Pacific Islander; Some Other Race P0010042
White; Black or African American; American Indian and Alaska Native; Asian P0010048
White; Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander P0010049
White; Black or African American; American Indian and Alaska Native; Some Other Race P0010050
White; Black or African American; Asian; Native Hawaiian and Other Pacific Islander P0010051
White; Black or African American; Asian; Some Other Race P0010052
White; Black or African American; Native Hawaiian and Other Pacific Islander; Some Other Race P0010053
Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander P0010058
Black or African American; American Indian and Alaska Native; Asian; Some Other Race P0010059
Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander; Some Other Race P0010060
Black or African American; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0010061
White; Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander P0010064
White; Black or African American; American Indian and Alaska Native; Asian; Some Other Race P0010065
White; Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander; Some Other Race P0010066
White; Black or African American; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0010067
Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0010069
White; Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0010071
```

Definition of Black by Census Codes (within **voting-age population**)

```
Black or African American alone P0030004
White; Black or African American P0030011
Black or African American; American Indian and Alaska Native P0030016
Black or African American; Asian P0030017
Black or African American; Native Hawaiian and Other Pacific Islander P0030018
Black or African American; Some Other Race P0030019
White; Black or African American; American Indian and Alaska Native P0030027
White; Black or African American; Asian P0030028
White; Black or African American; Native Hawaiian and Other Pacific Islander P0030029
White; Black or African American; Some Other Race P0030030
Black or African American; American Indian and Alaska Native; Asian P0030037
Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander P0030038
Black or African American; American Indian and Alaska Native; Some Other Race P0030039
Black or African American; Asian; Native Hawaiian and Other Pacific Islander P0030040
Black or African American; Asian; Some Other Race P0030041
Black or African American; Native Hawaiian and Other Pacific Islander; Some Other Race P0030042
White; Black or African American; American Indian and Alaska Native; Asian P0030048
White; Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander P0030049
White; Black or African American; American Indian and Alaska Native; Some Other Race P0030050
White; Black or African American; Asian; Native Hawaiian and Other Pacific Islander P0030051
White; Black or African American; Asian; Some Other Race P0030052
White; Black or African American; Native Hawaiian and Other Pacific Islander; Some Other Race P0030053
Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander P0030058
Black or African American; American Indian and Alaska Native; Asian; Some Other Race P0030059
Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander; Some Other Race P0030060
Black or African American; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0030061
White; Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander P0030064
White; Black or African American; American Indian and Alaska Native; Asian; Some Other Race P0030065
White; Black or African American; American Indian and Alaska Native; Native Hawaiian and Other Pacific Islander; Some Other Race P0030066
White; Black or African American; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0030067
Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0030069
White; Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander; Some Other Race P0030071
```

Definition of Black via Census products (within **citizen voting-age population**)

The 2015-2019 5-year ACS Special Tabulation produces 2010 tract-level estimates of citizen voting age population (CVAP) with some subpopulations. I selected the Non-Hispanic White (WCVAP), Non-Hispanic Black or African American (BCVAP), and Hispanic (HCVAP) categories. The 2015-2019 ACS also provides 2010 tract-level voting age population (VAP) estimates by tract, from which we use White (WVAP), Black or African American (BVAP), and Hispanic (HVAP). From these two products I have calculated the citizenship share for each subpopulation in each 2010 Census tract in Alabama. This citizenship share tracks, for example, BCVAP / BVAP—the share of non-Hispanic Black citizens of voting age over the total number of Black citizens, independent of ethnicity. To calculate 2020 CVAP estimates on 2020 Census blocks, I start with the 2020 PL-94 to determine the VAP share in each block for each subpopulation, then multiply by the corresponding citizenship share. For instance, we compute the 2020 BVAP count in each block $b$ (independent of ethnicity) and multiply it by the BCVAP / BVAP citizenship share assigned to the 2010 tract that contains $b$. An exactly similar method is used for WCVAP and HCVAP.

I declare under penalty of perjury that the foregoing is true and correct.

Executed this 10th day of December, 2021.

Moon Duchin

# Appendix A

# Moon Duchin

moon.duchin@tufts.edu - mduchin.math.tufts.edu
Mathematics · STS · Tisch College of Civic Life | Tufts University

## Education

**University of Chicago** MS 1999, PhD 2005
Mathematics
Advisor: Alex Eskin Dissertation: *Geodesics track random walks in Teichmüller space*

**Harvard University** BA 1998
Mathematics and Women's Studies

## Appointments

**Tufts University**
Professor of Mathematics 2021—
Assistant Professor, Associate Professor 2011–2021

*Director* | Program in Science, Technology, & Society 2015–2021
(on leave 2018–2019)

*Principal Investigator* | MGGG Redistricting Lab 2017—

*Senior Fellow* | Tisch College of Civic Life 2017—

**University of Michigan**
Assistant Professor (postdoctoral) 2008–2011

**University of California, Davis**
NSF VIGRE Postdoctoral Fellow 2005–2008

## Research Interests

Data science for civil rights, computation and governance, elections, geometry and redistricting.
Science, technology, and society, science policy, technology and law.
Random walks and Markov chains, random groups, random constructions in geometry.
Large-scale geometry, metric geometry, isoperimetric inequalities.
Geometric group theory, growth of groups, nilpotent groups, dynamics of group actions.
Geometric topology, hyperbolicity, Teichmüller theory.

## Awards & Distinctions

**Research Professor** - MSRI Program in Analysis and Geometry of Random Spaces Spring 2022
**Guggenheim Fellow** 2018
**Radcliffe Fellow** - Evelyn Green Davis Fellowship 2018–2019
**Fellow of the American Mathematical Society** elected 2017
**NSF C-ACCEL** (PI) - Harnessing the Data Revolution: Network science of Census data 2019–2020
**NSF grants** (PI) - CAREER grant and three standard Topology grants 2009–2022
**Professor of the Year**, Tufts Math Society 2012–2013
**AAUW Dissertation Fellowship** 2004–2005
**NSF Graduate Fellowship** 1998–2002
**Lawrence and Josephine Graves Prize for Excellence in Teaching** (U Chicago) 2002
**Robert Fletcher Rogers Prize** (Harvard Mathematics) 1995–1996

## Mathematics Publications & Preprints

***The (homological) persistence of gerrymandering***
Foundations of Data Science, online first. (with Thomas Needham and Thomas Weighill)

***You can hear the shape of a billiard table: Symbolic dynamics and rigidity for flat surfaces***
Commentarii Mathematici Helvetici, to appear. arXiv:1804.05690
(with Viveka Erlandsson, Christopher Leininger, and Chandrika Sadanand)

***Conjugation curvature for Cayley graphs***
Journal of Topology and Analysis, online first. (with Assaf Bar-Natan and Robert Kropholler)

***A reversible recombination chain for graph partitions***
*Preprint*. (with Sarah Cannon, Dana Randall, and Parker Rule)

***Recombination: A family of Markov chains for redistricting***
Harvard Data Science Review. Issue 3.1, Winter 2021. online. (with Daryl DeFord and Justin Solomon)

***Census TopDown: The impact of differential privacy on redistricting***
2nd Symposium on Foundations of Responsible Computing (FORC 2021), 5:1–5:22. online.
(with Aloni Cohen, JN Matthews, and Bhushan Suwal)

***Stars at infinity in Teichmüller space***
Geometriae Dedicata, Volume 213, 531–545 (2021). (with Nate Fisher) arXiv:2004.04321

***Random walks and redistricting: New applications of Markov chain Monte Carlo***
(with Daryl DeFord) For edited volume, Political Geometry. Under contract with Birkhäuser.

***Mathematics of nested districts: The case of Alaska***
Statistics and Public Policy. Vol 7, No 1 (2020), 39–51. (w/ Sophia Caldera, Daryl DeFord, Sam Gutekunst, & Cara Nix)

***A computational approach to measuring vote elasticity and competitiveness***
Statistics and Public Policy. Vol 7, No 1 (2020), 69–86. (with Daryl DeFord and Justin Solomon)

***The Heisenberg group is pan-rational***
Advances in Mathematics **346** (2019), 219–263. (with Michael Shapiro)

***Random nilpotent groups I***
IMRN, Vol 2018, Issue 7 (2018), 1921–1953. (with Matthew Cordes, Yen Duong, Meng-Che Ho, and Ayla Sánchez)

***Hyperbolic groups***
chapter in *Office Hours with a Geometric Group Theorist*, eds. M.Clay,D.Margalit, Princeton U Press (2017), 177–203.

***Counting in groups: Fine asymptotic geometry***
Notices of the American Mathematical Society **63**, No. 8 (2016), 871–874.

***A sharper threshold for random groups at density one-half***
Groups, Geometry, and Dynamics **10**, No. 3 (2016), 985–1005.
(with Katarzyna Jankiewicz, Shelby Kilmer, Samuel Lelièvre, John M. Mackay, and Ayla Sánchez)

***Equations in nilpotent groups***
Proceedings of the American Mathematical Society **143** (2015), 4723–4731. (with Hao Liang and Michael Shapiro)

***Statistical hyperbolicity in Teichmüller space***
Geometric and Functional Analysis, Volume 24, Issue 3 (2014), 748–795. (with Howard Masur and Spencer Dowdall)

***Fine asymptotic geometry of the Heisenberg group***
Indiana University Mathematics Journal 63 No. 3 (2014), 885–916. (with Christopher Mooney)

***Pushing fillings in right-angled Artin groups***
Journal of the LMS, Vol 87, Issue 3 (2013), 663–688. (with Aaron Abrams, Noel Brady, Pallavi Dani, and Robert Young)

***Spheres in the curve complex***
In the Tradition of Ahlfors and Bers VI, Contemp. Math. **590** (2013), 1–8. (with Howard Masur and Spencer Dowdall)

***The sprawl conjecture for convex bodies***
Experimental Mathematics, Volume 22, Issue 2 (2013), 113–122. (with Samuel Lelièvre and Christopher Mooney)

***Filling loops at infinity in the mapping class group***
Michigan Math. J., Vol 61, Issue 4 (2012), 867–874. (with Aaron Abrams, Noel Brady, Pallavi Dani, and Robert Young)

***The geometry of spheres in free abelian groups***
Geometriae Dedicata, Volume 161, Issue 1 (2012), 169–187. (with Samuel Lelièvre and Christopher Mooney)

***Statistical hyperbolicity in groups***
Algebraic and Geometric Topology **12** (2012) 1–18. (with Samuel Lelièvre and Christopher Mooney)

***Length spectra and degeneration of flat metrics***
Inventiones Mathematicae, Volume 182, Issue 2 (2010), 231–277. (with Christopher Leininger and Kasra Rafi)

***Divergence of geodesics in Teichmüller space and the mapping class group***
Geometric and Functional Analysis, Volume 19, Issue 3 (2009), 722–742. (with Kasra Rafi)

***Curvature, stretchiness, and dynamics***
In the Tradition of Ahlfors and Bers IV, Contemp. Math. **432** (2007), 19–30.

***Geodesics track random walks in Teichmüller space***
PhD Dissertation, University of Chicago 2005.

## Science, Technology, Law, and Policy Publications & Preprints

***Models, Race, and the Law***
Yale Law Journal Forum, Vol. 130 (March 2021). Available online. (with Doug Spencer)

***Computational Redistricting and the Voting Rights Act***
Election Law Journal, Available online. (with Amariah Becker, Dara Gold, and Sam Hirsch)

***Discrete geometry for electoral geography***
*Preprint*. (with Bridget Eileen Tenner) arXiv:1808.05860

***Implementing partisan symmetry: Problems and paradoxes***
Political Analysis, to appear. (with Daryl DeFord, Natasha Dhamankar, Mackenzie McPike, Gabe Schoenbach, and Ki-Wan Sim) arXiv:2008:06930

***Clustering propensity: A mathematical framework for measuring segregation***
*Preprint*. (with Emilia Alvarez, Everett Meike, and Marshall Mueller; appendix by Tyler Piazza)

***Locating the representational baseline: Republicans in Massachusetts***
Election Law Journal, Volume 18, Number 4, 2019, 388–401.
(with Taissa Gladkova, Eugene Henninger-Voss, Ben Klingensmith, Heather Newman, and Hannah Wheelen)

***Redistricting reform in Virginia: Districting criteria in context***
Virginia Policy Review, Volume XII, Issue II, Spring 2019, 120–146. (with Daryl DeFord)

***Geometry v. Gerrymandering***
*The Best Writing on Mathematics 2019*, ed. Mircea Pitici. Princeton University Press.
reprinted from Scientific American, November 2018, 48–53.

***Gerrymandering metrics: How to measure? What's the baseline?***
Bulletin of the American Academy for Arts and Sciences, Vol. LXII, No. 2 (Winter 2018), 54–58.

***Rebooting the mathematics of gerrymandering: How can geometry track with our political values?***
The Conversation (online magazine), October 2017. (with Peter Levine)

***A formula goes to court: Partisan gerrymandering and the efficiency gap***
Notices of the American Mathematical Society **64** No. 9 (2017), 1020–1024. (with Mira Bernstein)

***International mobility and U.S. mathematics***
Notices of the American Mathematical Society **64**, No. 7 (2017), 682–683.

## Graduate Advising in Mathematics

Nate Fisher (PhD 2021), Sunrose Shrestha (PhD 2020), Ayla Sánchez (PhD 2017), Kevin Buckles (PhD 2015), Mai Mansouri (MS 2014)

Outside committee member for Chris Coscia (PhD 2020), Dartmouth College

## Postdoctoral Advising in Mathematics

**Principal supervisor** Thomas Weighill (2019–2020)

**Co-supervisor** Daryl DeFord (MIT 2018–2020), Rob Kropholler (2017–2020), Hao Liang (2013–2016)

## Teaching

### Courses Developed or Customized

**Mathematics of Social Choice** | sites.tufts.edu/socialchoice
Voting theory, impossibility theorems, redistricting, theory of representative democracy, metrics of fairness.

**History of Mathematics** | sites.tufts.edu/histmath
Social history of mathematics, organized around episodes from antiquity to present. Themes include materials and technologies of creation and dissemination, axioms, authority, credibility, and professionalization. In-depth treatment of mathematical content from numeration to cardinal arithmetic to Galois theory.

**Reading Lab: Mathematical Models in Social Context** | sites.tufts.edu/models
One hr/wk discussion seminar of short but close reading on topics in mathematical modeling, including history of psychometrics; algorithmic bias; philosophy of statistics; problems of model explanation and interpretation.

**Geometric Literacy**
Module-based graduate topics course. Modules have included: $p$-adic numbers, hyperbolic geometry, nilpotent geometry, Lie groups, convex geometry and analysis, the complex of curves, ergodic theory, the Gauss circle problem.

**Markov Chains** (graduate topics course)
**Teichmüller Theory** (graduate topics course)
**Fuchsian Groups** (graduate topics course)
**Continued Fractions and Geometric Coding** (undergraduate topics course)
**Mathematics for Elementary School Teachers**

### Standard Courses

Discrete Mathematics, Calculus I-II-III, Intro to Proofs, Linear Algebra, Complex Analysis, Differential Geometry, Abstract Algebra, Graduate Real Analysis, Mathematical Modeling and Computation

### Weekly Seminars Organized

- Geometric Group Theory and Topology
- Science, Technology, and Society Lunch Seminar

## Selected Talks and Lectures

**Distinguished Plenary Lecture** June 2021
75th Anniversary Meeting of Canadian Mathematical Society, Ottawa, Ontario *online (COVID)*

**BMC/BAMC Public Lecture** April 2021
Joint British Mathematics/Applied Mathematics Colloquium, Glasgow, Scotland *online (COVID)*

**AMS Einstein Public Lecture in Mathematics** [March 2020]
Southeastern Sectional Meeting of the AMS, Charlottesville, VA *postponed*

**Gerald and Judith Porter Public Lecture**
AMS-MAA-SIAM, Joint Mathematics Meetings, San Diego, CA January 2018

**Mathematical Association of America Distinguished Lecture**
MAA Carriage House, Washington, DC October 2016

**American Mathematical Society Invited Address**
AMS Eastern Sectional Meeting, Brunswick, ME September 2016

### Named University Lectures

- Parsons Lecture | UNC Asheville October 2020
- Loeb Lectures in Mathematics | Washington University in St. Louis [March 2020]
- Math, Stats, CS, and Society | Macalester College October 2019
- MRC Public Lecture | Stanford University May 2019
- Freedman Memorial Colloquium | Boston University March 2019
- Julian Clancy Frazier Colloquium Lecture | U.S. Naval Academy January 2019
- Barnett Lecture | University of Cincinnati October 2018
- School of Science Colloquium Series | The College of New Jersey March 2018
- Kieval Lecture | Cornell University February 2018
- G. Milton Wing Lectures | University of Rochester October 2017
- Norman Johnson Lecture | Wheaton College September 2017
- Dan E. Christie Lecture | Bowdoin College September 2017

### Math/Computer Science Department Colloquia

- Reed College Dec 2020
- Georgetown (CS) Sept 2020
- Santa Fe Institute July 2020
- UC Berkeley Sept 2018
- Brandeis-Harvard-MIT-NEU Mar 2018
- Northwestern University Oct 2017
- University of Illinois Sept 2017
- University of Utah Aug 2017
- Wesleyan Dec 2016
- Worcester Polytechnic Inst. Dec 2016
- Université de Neuchâtel Jun 2016
- Brandeis University Mar 2016
- Swarthmore College Oct 2015
- Bowling Green May 2015
- City College of New York Feb 2015
- Indiana University Nov 2014
- the Technion Oct 2014
- Wisconsin–Madison Sept 2014
- Stony Brook March 2013

### Minicourses

- Integer programming and combinatorial optimization (two talks) | Georgia Tech — May 2021
- Workshop in geometric topology (main speaker, three talks) | Provo, UT — June 2017
- Growth in groups (two talks) | MSRI, Berkeley, CA — August 2016
- Hyperbolicity in Teichmüller space (three talks) | Université de Grenoble — May 2016
- Counting and growth (four talks) | IAS Women's Program, Princeton — May 2016
- Nilpotent groups (three talks) | Seoul National University — October 2014
- Sub-Finsler geometry of nilpotent groups (five talks) | Galatasaray Univ., Istanbul — April 2014

### Science, Technology, and Society

- The Mathematics of Accountability | Sawyer Seminar, Anthropology, Johns Hopkins — February 2020
- STS Circle | Harvard Kennedy School of Government — September 2019
- Data, Classification, and Everyday Life Symposium | Rutgers Center for Cultural Analysis — January 2019
- Science Studies Colloquium | UC San Diego — January 2019
- Arthur Miller Lecture on Science and Ethics | MIT Program in Science, Tech, and Society — November 2018

### Data Science, Computer Science, Quantitative Social Science

- Data Science for Social Good Workshop (DS4SG) | Georgia Tech (virtual) — November 2020
- Privacy Tools Project Retreat | Harvard (virtual) — May 2020
- Women in Data Science Conference | Microsoft Research New England — March 2020
- Quantitative Research Methods Workshop | Yale Center for the Study of American Politics — February 2020
- Societal Concerns in Algorithms and Data Analysis | Weizmann Institute — December 2018
- Quantitative Collaborative | University of Virginia — March 2018
- Quantitative Social Science | Dartmouth College — September 2017
- Data for Black Lives Conference | MIT — November 2017

### Political Science, Geography, Law, Democracy, Fairness

- The Long 19th Amendment: Women, Voting, and American Democracy | Radcliffe Institute — Nov–Dec 2020
- "The New Math" for Civil Rights | Social Justice Speaker Series, Davidson College — November 2020
- Math, Law, and Racial Fairness | Justice Speaker Series, University of South Carolina — November 2020
- Voting Rights Conference | Northeastern Public Interest Law Program — September 2020
- Political Analysis Workshop | Indiana University — November 2019
- Program in Public Law Panel | Duke Law School — October 2019
- Redistricting 2021 Seminar | University of Chicago Institute of Politics — May 2019
- Geography of Redistricting Conference Keynote | Harvard Center for Geographic Analysis — May 2019
- Political Analytics Conference | Harvard University — November 2018
- Cyber Security, Law, and Society Alliance | Boston University — September 2018
- Clough Center for the Study of Constitutional Democracy | Boston College — November 2017
- Tech/Law Colloquium Series | Cornell Tech — November 2017
- Constitution Day Lecture | Rockefeller Center for Public Policy, Dartmouth College — September 2017

## Editorial Boards

**Harvard Data Science Review**
Associate Editor — since 2019

**Advances in Mathematics**
Member, Editorial Board — since 2018

## Selected Professional and Public Service

**Amicus Brief of Mathematicians, Law Professors, and Students** 2019
*principal co-authors: Guy-Uriel Charles and Moon Duchin*
Supreme Court of the United States, in Rucho v. Common Cause - cited in dissent

**Committee on Science Policy** 2020–2023
American Mathematical Society

**Program Committee** 2020–2021
Symposium on Foundations of Responsible Computing

**Presenter on Public Mapping, Statistical Modeling** 2019, 2020
National Conference of State Legislatures

**Committee on the Human Rights of Mathematicians** 2016–2019
American Mathematical Society

**Committee on The Future of Voting: Accessible, Reliable, Verifiable Technology** 2017–2018
National Academies of Science, Engineering, and Medicine

## Visiting Positions and Residential Fellowships

**Visiting Professor** Department of Mathematics Fall 2021
Boston College | Chestnut Hill, MA

**Fellow** Radcliffe Institute for Advanced Study 2018–19
Harvard University | Cambridge, MA

**Member** Center of Mathematical Sciences and Applications 2018–19
Harvard University | Cambridge, MA

**Visitor** Microsoft Research Lab 2018–19
MSR New England | Cambridge, MA

**Research Member** Geometric Group Theory program Fall 2016
Mathematical Sciences Research Institute | Berkeley, CA

**Research Member** Random Walks and Asymptotic Geometry of Groups program Spring 2014
Institut Henri Poincaré | Paris, France

**Research Member** Low-dimensional Topology, Geometry, and Dynamics program Fall 2013
Institute for Computational and Experimental Research in Mathematics | Providence, RI

**Research Member** Geometric and Analytic Aspects of Group Theory program May 2012
Institut Mittag-Leffler | Stockholm, Sweden

**Research Member** Quantitative Geometry program Fall 2011
Mathematical Sciences Research Institute | Berkeley, CA

**Postdoctoral Fellow** Teichmüller "project blanc" Spring 2009
Agence Nationale de la Recherche (Collège de France) | Paris, France