

2021 Illinois Congressional Redistricting Analysis (maps updated with 2020 census data and five majority-minority districts each)

Kiera W. Dobbs, Rahul Swamy, Douglas M. King

Department of Industrial and Enterprise Systems Engineering, University of Illinois Urbana-Champaign, Urbana, IL 61801
kdobbs2@illinois.edu, rahulswa@illinois.edu, dmking@illinois.edu

Ian G. Ludden, Sheldon H. Jacobson

Department of Computer Science, University of Illinois Urbana-Champaign, Urbana, IL, 61801
iludden2@illinois.edu, shj@illinois.edu

15 December 2021 (originally posted 9 August 2021)

This research analysis was conducted as part of the Institute for Computational Redistricting (ICOR) at the University of Illinois at Urbana-Champaign. This activity was conducted in a non-partisan manner, with any political descriptors used reflecting the results of the quantitative analysis, not the opinions of the researchers nor ICOR.

Contents

Executive Summary	3
1 Introduction	5
2 Fairness Metrics	5
3 Optimization Method	9
4 Redistricting in Illinois	10
4.1 Data Sources	10
4.2 Constitutional Requirements	11
5 District Plans	13
5.1 Compact Plans	14
5.2 Efficiency Gap Plans	14
5.3 Partisan Asymmetry Plans	14
5.4 Competitive Plans	14
6 Discussion	23
6.1 Limitations	26
A Additional Technical Details	27

Executive Summary

The Institute for Computational Redistricting (<http://redistricting.cs.illinois.edu>) is a research group at the University of Illinois at Urbana-Champaign. Under the direction of Dr. Sheldon H. Jacobson (<http://shj.cs.illinois.edu>) and Dr. Douglas M. King, the group focuses on computational methods for redistricting to provide transparency within the redistricting process. Since Illinois lost a congressional seat following the 2020 census, a new congressional district plan cannot simply maintain the cores of the current districts; all districts must have a larger population, to compensate for the lost seat. Completely redrawing district boundaries provides an opportunity to improve fairness and transparency in the districting process. The goal of this analysis is to examine the partisan characteristics of Illinois congressional district plans with 17 districts (instead of 18) that satisfy constitutional requirements.

We use an optimization algorithm to create a diverse collection of eight congressional district plans for Illinois that satisfy constitutional requirements and prioritize different fairness objectives (e.g., compactness, the Efficiency Gap). Although Illinois does not have additional congressional redistricting requirements (beyond those required by the U.S. Constitution), focusing on multiple aspects of fairness can illustrate how constitutional requirements and political geography affect the level of political fairness achievable for Illinois. It is also important to create these district plans by transparent means; with no insight into how a plan was constructed, it is not clear whether undesirable qualities (e.g., packing and cracking, non-competitive districts) can be attributed to gerrymandering or whether they arise from other factors such as constitutional requirements or political geography. Optimization algorithms promote transparency in each step of the redistricting process, since they have clearly defined objectives, constraints, and parameters. A discussion accompanies the collection of district plans, including the advantages and disadvantages of each plan, and how legal requirements and political geography impact the redistricting process.

Ultimately, the results show that there are multiple options for the Illinois congressional district plan that achieve a good level of political fairness while a) maintaining five majority-minority districts and b) maintaining reasonably compact districts. This conclusion is based on the following observations:

- District plans created to solely prioritize compactness tend to pack Democratic voters, since Democrats are heavily concentrated in the Chicago area.

- In contrast, district plans created to prioritize the Efficiency Gap, Partisan Asymmetry, or competitiveness *and* maintain compactness have better levels of political fairness, and tend to have district shapes comparable to plans that *solely* prioritize compactness.

1. Introduction

Illinois lost a congressional seat following the 2020 census. Therefore, a new congressional district plan cannot simply maintain the cores of the current districts; all districts must have a larger population, to compensate for the lost seat. Completely redrawing district boundaries provides an opportunity to improve fairness and transparency in the districting process.

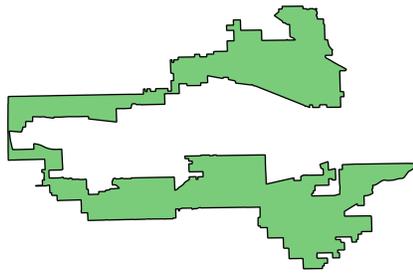
This report presents a diverse collection of eight congressional district plans for Illinois. The plans are constructed with an optimization algorithm to promote transparency in the districting process. Some plans presented in this report prioritize compactness, while others prioritize aspects of partisan fairness (e.g., the Efficiency Gap). Although the Illinois Constitution does not list additional state requirements for congressional redistricting, focusing on multiple aspects of fairness allows one to examine how requirements from the U.S. Constitution (e.g., majority-minority districts) and political geography affect the level of political fairness achievable for Illinois. Each plan is scored with various fairness metrics, and the advantages and disadvantages between plans are discussed. The results show that compactness *and* good political fairness are achievable for Illinois congressional district plans.

This report is organized as follows. Section 2 describes the fairness metrics used to evaluate district plans. Section 3 gives an overview of the optimization method used to construct the plans that optimize these fairness metrics. Section 4 outlines redistricting requirements in the U.S. Constitution and relevant data. Lastly, Section 5 presents the district plans and Section 6 discusses and compares their partisan characteristics.

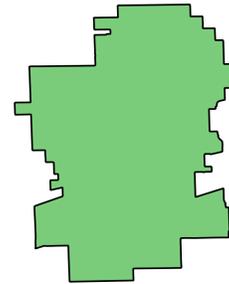
2. Fairness Metrics

In the context of redistricting, “fairness” can be interpreted in a number of ways. Sometimes fairness focuses on political parties; for example, a district plan could be considered fair if neither party is *packed* and *cracked* (i.e., concentrated in a few districts where it wins by overwhelming margins, then diluted among the remaining districts). Fairness can also mean reasonably shaped districts, or competitive districts. Throughout this report, we refer to metrics that use voting data as *partisan fairness metrics*; compactness is the only fairness metric considered in this report that is not a partisan fairness metric. Each district plan presented in this report is evaluated with various metrics that quantify these common aspects of fairness. This section gives an overview of each metric.

- Compactness: A district is compact if it has a simple shape (such as a circle or square, as in Figure 1b), as opposed to a convoluted shape (as in Figure 1a). Simple shapes are preferred, since convoluted district shapes can be a result of intentional boundary manipulation for political gain. For example, the salamander-shaped Massachusetts district that inspired the term *gerrymander* in 1812 was constructed to pack Federalist voters (Griffith 1907). There are several ways one could quantify district compactness (Young 1988); we choose to measure compactness as the sum of all district perimeters (reported in miles). We exclude perimeter segments that coincide with Illinois’s state boundary, since the state boundary will always overlap with district perimeter segments for any district plan. A district with an irregular shape (such as Illinois’s fourth congressional district from the 2011 redistricting cycle in Figure 1a) has a larger perimeter than a district with a simpler shape (as in Figure 1b), which means that smaller values of this metric indicate more compact districts.



(a) Illinois’s fourth congressional district from the 2011 redistricting cycle (U.S. Census Bureau 2020c) with a perimeter of approximately 220 miles

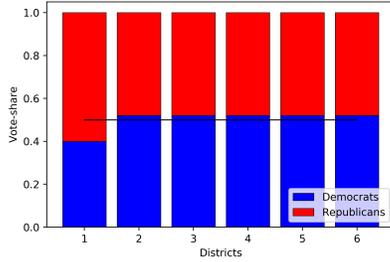


(b) A compact district with a perimeter of approximately 87 miles

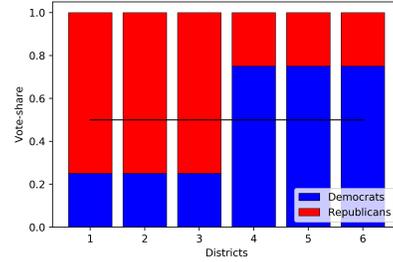
Figure 1 Two examples of district shapes (for roughly the same location in the Chicago area). Figure 1a shows a non-compact district and Figure 1b shows a compact district.

- Efficiency Gap: The Efficiency Gap aims to quantify packing and cracking. A packed party wastes votes because it wins districts by overwhelming margins; a cracked party wastes votes because it narrowly loses many districts. Hence, “wasted votes” are votes cast for a district’s losing party, or votes cast for a district’s winning party in excess of the 50% needed to win the election. The Efficiency Gap measures the difference in wasted votes between both parties and reports this difference as a percentage of the total votes cast for these two parties (Stephanopoulos and McGhee 2015). Smaller

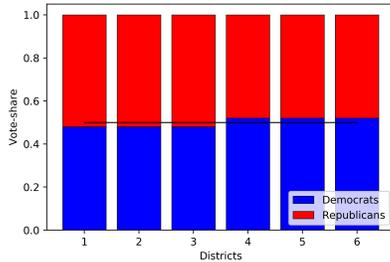
values of this metric indicate that both parties waste a similar number of votes, which means both parties are packed and cracked to a similar degree. For example, the vote-share scenario in Figure 2a has a large Efficiency Gap because Republicans are cracked, and therefore waste many votes; the vote-share scenarios in Figures 2b, 2c, and 2d have small Efficiency Gap values, because both parties waste votes equally.



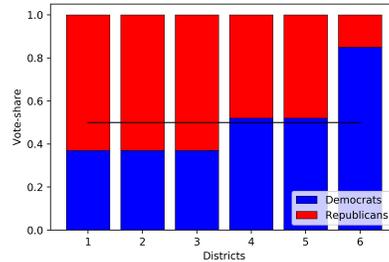
(a) Democrats win five seats and Republicans win one seat. Five seats are competitive. The Efficiency Gap is bad because Republicans are cracked. Partisan Asymmetry is good because the district vote-shares are mostly symmetrically distributed.



(b) Democrats and Republicans each win three seats. No seats are competitive. The Efficiency Gap is good because both parties waste votes equally. Partisan Asymmetry is good because the district vote-shares are symmetrically distributed.



(c) Democrats and Republicans each win three seats. All seats are competitive. The Efficiency Gap is good because both parties waste votes equally. Partisan Asymmetry is good because the district vote-shares are symmetrically distributed.



(d) Democrats and Republicans each win three seats. Two seats are competitive. The Efficiency Gap is good because both parties waste votes equally. Partisan Asymmetry is bad because the district vote-shares are asymmetrically distributed.

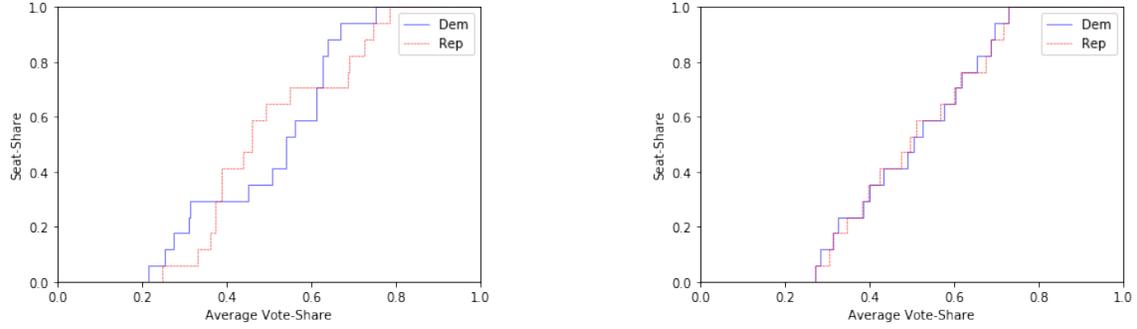
Figure 2 Example vote-share scenarios for six districts. Although the overall vote-share is split 50-50 (assuming equal turnout in all districts), there are a number of ways the voters can be grouped into districts.

- Partisan Asymmetry: Partisan Asymmetry observes to what extent both parties receive different seat outcomes for the same vote-share scenarios (Grofman and King 2007). Partisan Asymmetry compares the rate at which both parties win/lose seats as the statewide vote-share shifts uniformly among all districts. As the vote-share for

one party gradually increases to 100% or decreases to 0%, we can observe how many seats that party would hypothetically win for each of those vote-share scenarios. For example, Figure 3 shows the number of seats each party would hypothetically win for vote-shares from 0-100% in two example district plans (these plots are called *vote-seat curves*). The more space that exists between the two curves, the more asymmetry is present in the district plan. For the plan in Figure 3a, if Democrats and Republicans were to both win 50% of the votes, they would win roughly 35% and 65% of the seats, respectively. However, for the plan in Figure 3b, Democrats and Republicans each win roughly 50% of the seats for 50% of the votes. In general, there is a large amount of space between the two curves in Figure 3a, while the curves in Figure 3b are nearly identical. Therefore, the plan in Figure 3b is more symmetric than the plan in Figure 3a. The Partisan Asymmetry metric value is calculated as the area between both parties' vote-seat curves (Grofman 1983). This metric typically takes on values between 0.00 and 0.11. The minimum value of zero occurs when the vote-seat curves are exactly the same; however, sometimes factors such as political geography or number of districts can prevent a state from achieving a value of zero. Similarly, the largest value achievable varies slightly from state to state. As a rough guideline, smaller values up to 0.01 indicate very symmetric plans, while larger values such as 0.08-0.11 indicate very asymmetric plans.

As additional examples, the vote-share scenarios in Figures 2b and 2c have small Partisan Asymmetry values because the vote-shares are symmetrically distributed (i.e., both parties are spread evenly across the districts). The vote-share scenario in Figure 2d has a large Partisan Asymmetry value because the vote-shares are asymmetrically distributed.

- Competitiveness: Maintaining competitive districts can encourage voter turnout, reduce district packing, and discourage candidate complacency (Hirano and Snyder 2012, McCarty et al. 2009, Tapp 2018). To assess the competitiveness of a district plan, we display the Democrat/Republican vote-share in each district and report the number of districts within a 10% margin of victory. For example, the vote-shares scenarios in Figures 2a and 2c have many competitive districts, while the scenario in Figure 2b has no competitive districts.



(a) The vote-seat curves of an asymmetric plan

(b) The vote-seat curves of a symmetric plan

Figure 3 Vote-seat curves for Democrats and Republicans. The curves in Figure 3a are for an asymmetric district plan and the curves in Figure 3b are for a symmetric district plan.

3. Optimization Method

This section describes how the optimization algorithm constructs district plans. In general, the algorithm aims to find a district plan with the best fairness metric value, within the constraints of legal requirements. The algorithm is called a *local search* method, meaning it starts with a given district plan (e.g., the plan currently in place, or another proposed plan) and improves it by making a sequence of small changes to district boundaries. While a single small change might not drastically transform the plan, performing thousands of them can lead to a significant improvement as the algorithm continues to run. The basic steps of the algorithm, based on a method from DeFord et al. (2019), are listed below. Appendix A provides additional details for algorithm application (including parameter choices and number of iterations).

1. Choose an initial district plan, a fairness metric to improve (e.g., compactness, Efficiency Gap), and constraints to enforce (e.g., roughly equal district populations).
2. Randomly choose two neighboring districts.
3. Erase the boundary between these two districts and randomly draw a new boundary that maintains contiguity. Note that this action only affects the two chosen districts.
4. Check whether this new boundary satisfies the constraints chosen in Step 1. If it does not, return to Step 3. If it does, continue to Step 5.
5. Check whether this new boundary improves the chosen fairness metric. If it does not, return to Step 3. If it does, continue to Step 6.
6. Record this boundary. Repeat Steps 3-5 to create a collection of viable new boundaries.

7. From the collection of viable boundaries, select the boundary that yields the greatest improvement in the fairness metric. Update the district plan accordingly. Repeat Steps 2-6 as needed.

Figure 4 shows an example sequence of changes to improve compactness in a three-district plan, using counties as district building blocks. The initial plan (Figure 4a) has convoluted districts with tendrils. Each algorithm iteration makes the boundary between two districts less convoluted. After three iterations, there are no tendrils and the districts have simpler shapes (Figure 4d).

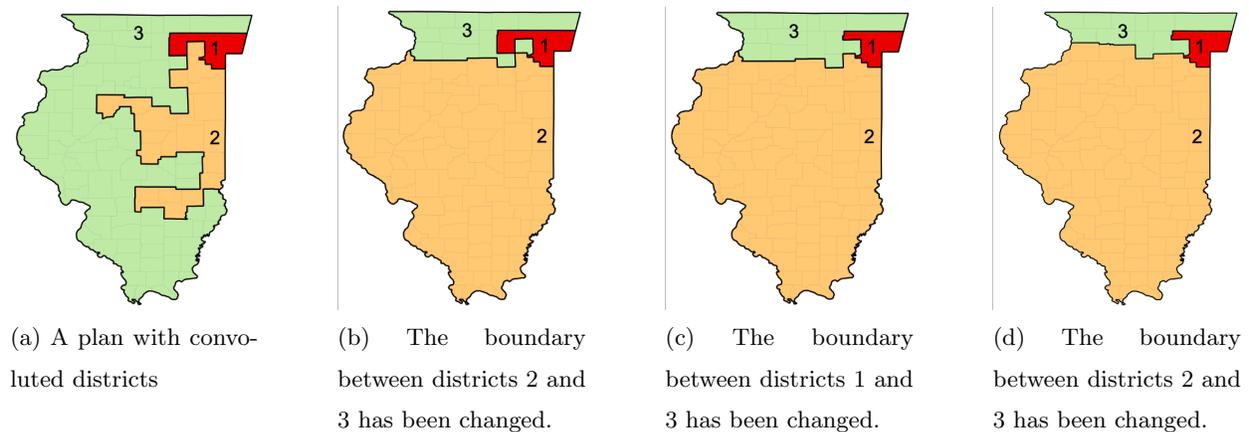


Figure 4 Example iterations of the optimization algorithm using a three-district plan at the county level. Each iteration shows which two districts are changed to improve compactness.

4. Redistricting in Illinois

This section describes how congressional redistricting is conducted in Illinois. We discuss the political geography of Illinois, the data sources used for our experiments, and the redistricting requirements in the U.S. Constitution.

4.1. Data Sources

Congressional redistricting in Illinois requires data describing state geography, population, demographics, and election results. The data sources used to create district plans for this report are listed below.

- *State geography*: Districts are constructed using geographic units, such as census blocks, census block groups, census tracts, and counties. The U.S. Census Bureau provides spatial data for these units (U.S. Census Bureau 2020c). With spatial data,

we can determine which units are neighbors (to enforce district contiguity) and the length of shared borders between neighboring units (to calculate district perimeters for compactness).

- Population: In addition to spatial data, the U.S. Census Bureau also provides population counts for geographic units from the 2020 decennial census (U.S. Census Bureau 2020b). Population data are needed to ensure that all districts have roughly equal populations.
- Demographics: To comply with the Voting Rights Act of 1965, states typically construct majority-minority districts (Ballotpedia 2015). To maintain such districts, we use demographic data from the 2020 decennial census (U.S. Census Bureau 2020a,b).
- Election results: While compactness can be calculated with spatial data (i.e., state geography data), the other fairness metrics in Section 2 rely on voting data from past elections. To construct districts using finer census units (e.g., census tracts), voting data must be disaggregated from the precinct level to the finer level. In this report, we construct and analyze plans using precinct-level voting data (distributed proportionally to census blocks) from the races for governor, United States Senate, and President in the 2016, 2018, and 2020 general elections (Voting and Election Science Team 2021).

We can also use the voting data to examine Illinois’s political geography. According to this set of data, Illinois is roughly 58.3% Democrat and 41.7% Republican. Figure 5 shows which census blocks lean Democrat and which lean Republican. Democratic voters are concentrated in urban centers (such as Chicago), while Republicans are spread throughout the state.

4.2. Constitutional Requirements

The U.S. Constitution requires congressional districts to be equi-populous and comply with the Voting Rights Act of 1965 (National Conference of State Legislatures 2021); the Illinois Constitution does not impose additional requirements for congressional redistricting. Below we list how the plans in this report satisfy these requirements.

- Population balance: Typically, congressional district populations deviate from the ideal district population (i.e., the total state population divided by the number of districts) by at most one person (National Conference of State Legislatures 2021). Single-person population balance is achievable when districts are constructed with

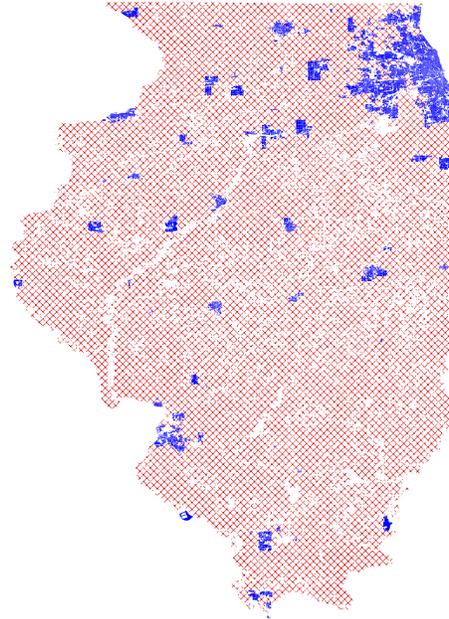


Figure 5 Voting data for the entire state of Illinois. Democratic blocks are shown in solid blue, Republican blocks are shown in hatched red, and blocks without voters are shown in white. Democratic voters are concentrated in urban centers (such as Chicago), while Republicans are more evenly distributed throughout the state.

census blocks, the smallest geographic census unit. For computational efficiency, the plans in this report are constructed with counties and census tracts (a larger census unit); hence, we allow districts to deviate by at most 0.5% from the ideal population. The plans presented can then be manually tuned to single-person population balance using census blocks without significantly altering district characteristics (e.g., compactness, partisan fairness).

- Voting Rights Act: The new 2021 Illinois congressional plan has five majority-minority districts: three districts with Black/African-American majorities/pluralities and two districts with Latino/Hispanic majorities/pluralities (Illinois House Democrats 2021). Each of the district plans in this report has five majority-minority districts with similar compositions.

Although not explicitly required, all plans in this report are contiguous and reasonably compact; some plans are explicitly optimized for compactness, while others are optimized for different fairness metrics. In the latter cases, compactness is maintained as much as possible.

5. District Plans

Here we present a collection of congressional district plans for Illinois, following the constitutional requirements discussed in Section 4.2 and optimized for the different fairness metrics discussed in Section 2.

Illinois lost a congressional seat following the 2020 census; now there are 17 congressional districts and the ideal district population is 753,677 people. As mentioned in Section 4.2, district populations deviate from the ideal population by at most 0.5%, which allows a difference of at most 7,536 people between the most populated and least populated congressional districts. The congressional plans are constructed with a combination of 20 counties and 3,206 census tracts; the 20 least populated counties are kept intact and the remaining counties are split into census tracts. Splitting more counties into tracts at the beginning gives the algorithm more flexibility to find good plans; note that the final plans have more than 20 counties intact, since optimizing for compactness tends to preserve county lines as well.

The district plans in this section can be categorized in the following manner. For each type of plan, we provide two different options.

- Compact plans: These plans were optimized solely for compactness. No effort was made to improve other fairness metrics.
- Efficiency Gap plans: First, these plans were optimized for the Efficiency Gap (i.e., the algorithm tries to make this value as small as possible). Once the plans have a small Efficiency Gap value, the algorithm maintains this small value while improving compactness.
- Partisan Asymmetry plans: Similar to the approach taken to produce the Efficiency Gap plans, the algorithm first decreases the Partisan Asymmetry value as much as possible, and then improves compactness while maintaining a small value.
- Competitive plans: For these plans, the algorithm simultaneously improves compactness and competitiveness; every competitive district encountered while improving compactness is maintained.

Note that we construct some sets of district plans with multiple algorithm phases (i.e., first a plan is optimized for a partisan fairness metric, then the plan is optimized for compactness). Appendix A gives additional details for plan construction, including a discussion of these phases.

5.1. Compact Plans

Figures 6 and 7 display the compact congressional plans (COMP1 and COMP2, respectively). The districts in these plans are fairly circular/rectangular, even in the Chicago area. The majority-minority districts tend to be more elongated (Figures 6b and 7b), but remain reasonably shaped.

5.2. Efficiency Gap Plans

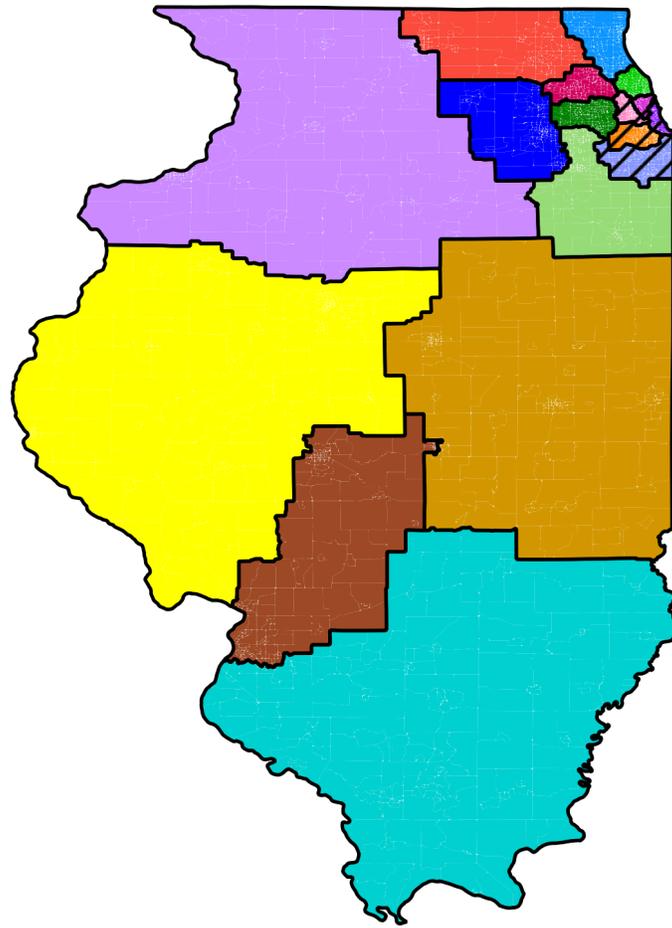
Figures 8 and 9 display the Efficiency Gap congressional plans (EG1 and EG2, respectively). The district shapes are reasonable and comparable to the compact plans. The districts in the Chicago area have shapes similar to the compact plans (Figures 8b and 9b). COMP1/2 both have a district that is relatively localized in the St. Louis area; in contrast, EG1 has a district that reaches from the St. Louis area to the south-east (Figure 8a) and EG2 has a district that reaches from the St. Louis area to the north-west (Figure 9a). However, even these longer districts are reasonably rectangular; slight differences in district shapes may be a result of the algorithm trying to more evenly distribute voters among the districts.

5.3. Partisan Asymmetry Plans

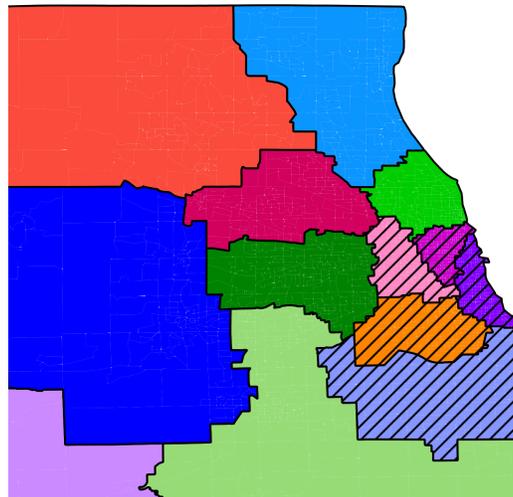
Figures 10 and 11 display the Partisan Asymmetry congressional plans (PA1 and PA2, respectively). Both plans have more irregular district shapes than COMP1/2. In PA1, a few districts in the Chicago area are elongated and one is lobster-shaped (Figure 10b); in PA2, there is one large district that reaches from the north-west to the east (Figure 11a) and one district in the Chicago area has a small tendril (Figure 11b). This likely results from the majority-minority districts maintaining a majority-minority population in addition to redistributing their typically high concentration of Democratic voters.

5.4. Competitive Plans

Figures 12 and 13 display the competitive congressional plans (CMPTTV1 and CMPTTV2, respectively). As with the Efficiency Gap plans, the district shapes are largely comparable to the compact plans. The only slightly unusual district shape is an elongated majority-minority district in CMPTTV1 (Figure 12b). This suggests that creating more competitive districts only requires minor adjustments to district boundaries.

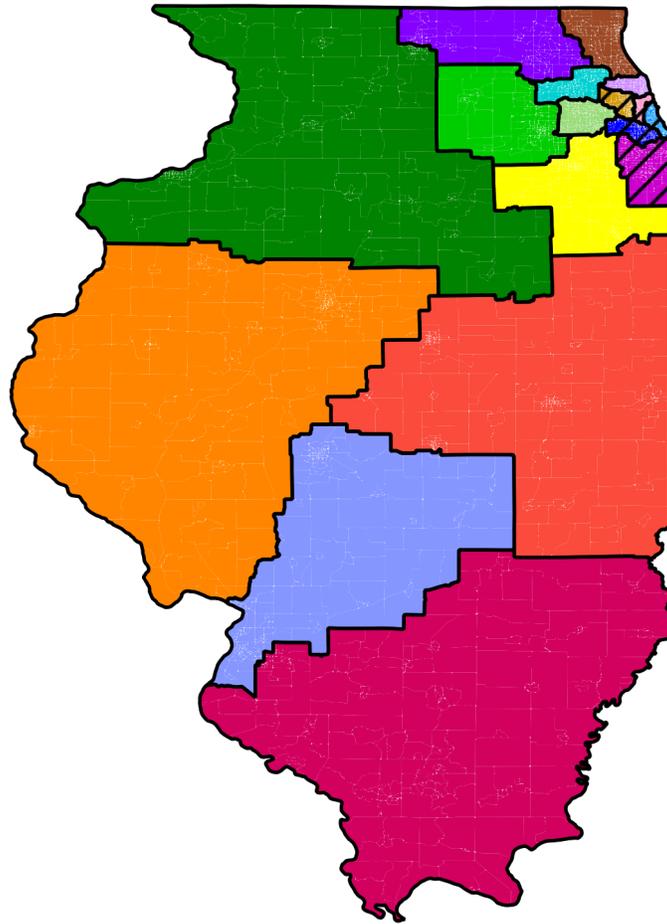


(a) COMP1

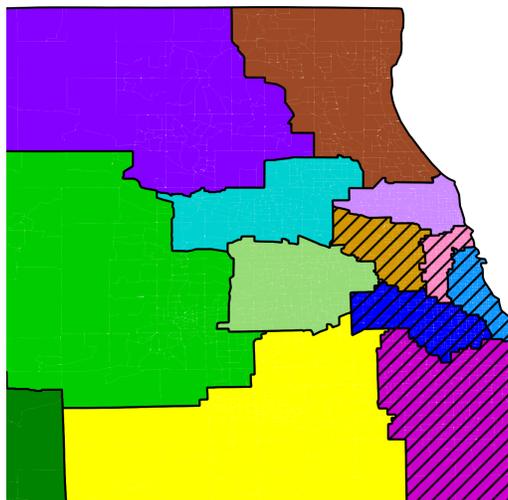


(b) The Chicago area

Figure 6 A congressional plan optimized for compactness (COMP1), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

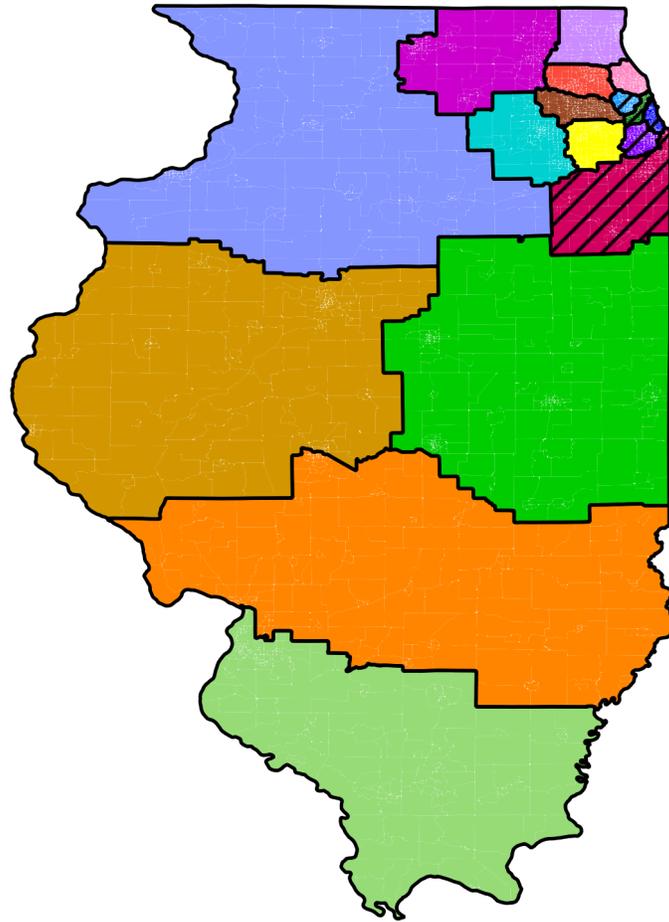


(a) COMP2

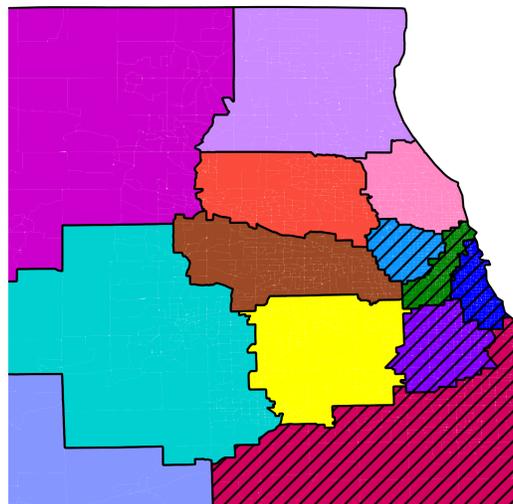


(b) The Chicago area

Figure 7 A congressional plan optimized for compactness (COMP2), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

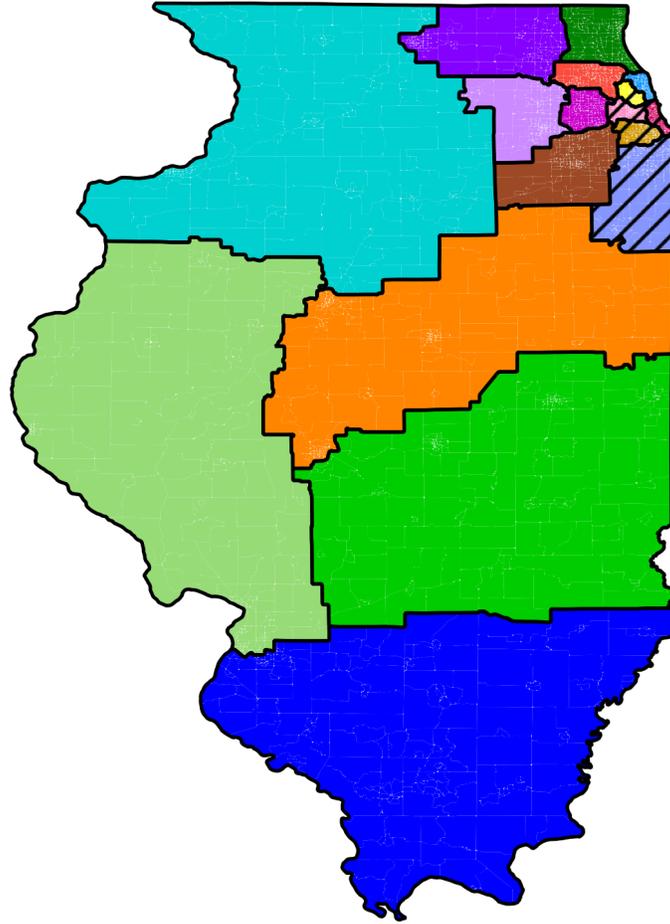


(a) EG1

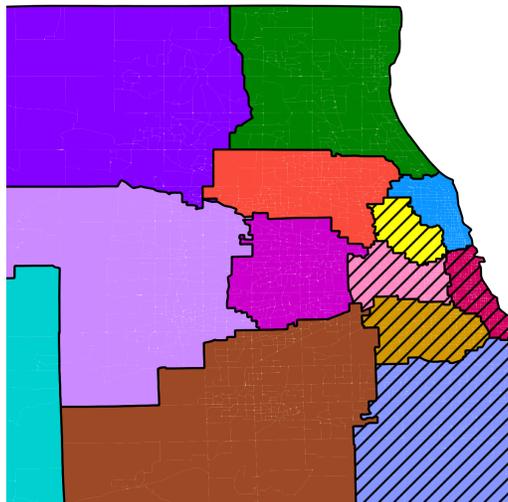


(b) The Chicago area

Figure 8 A congressional plan optimized for the Efficiency Gap (EG1), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

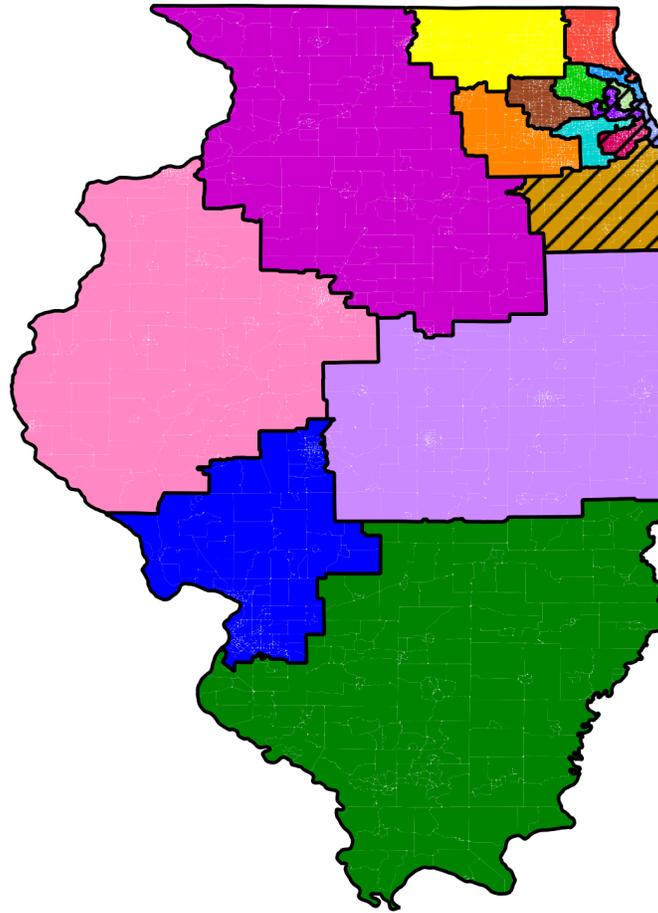


(a) EG2

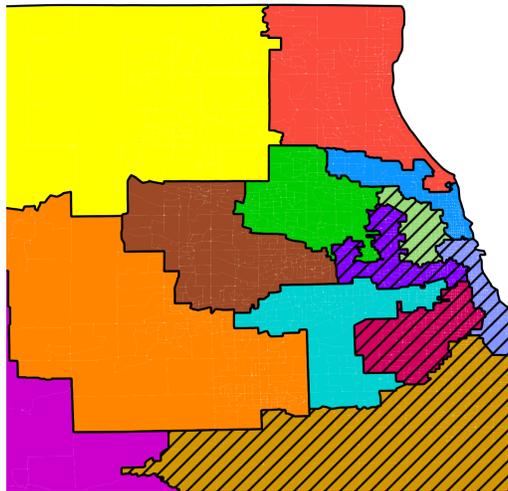


(b) The Chicago area

Figure 9 A congressional plan optimized for the Efficiency Gap (EG2), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

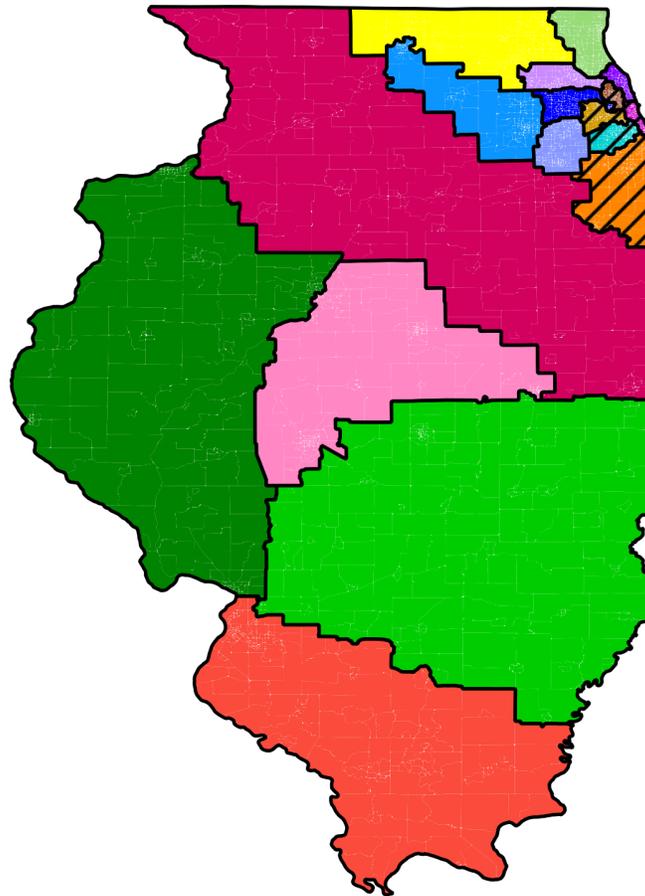


(a) PA1

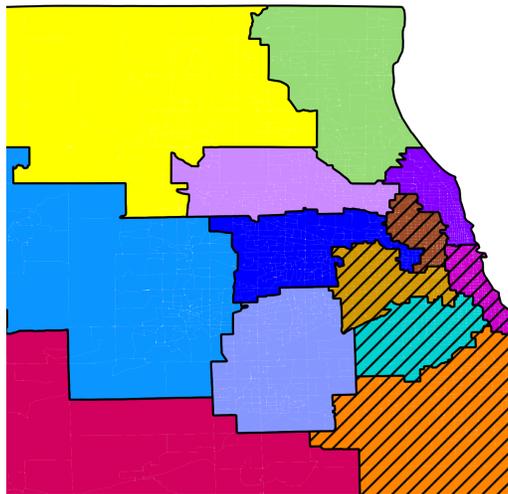


(b) The Chicago area

Figure 10 A congressional plan optimized for Partisan Asymmetry (PA1), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

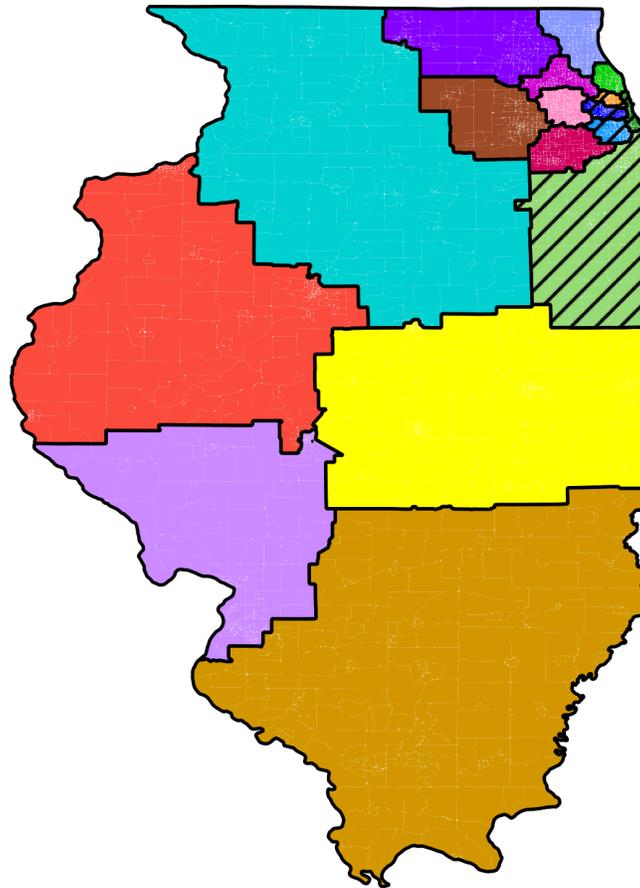


(a) PA2

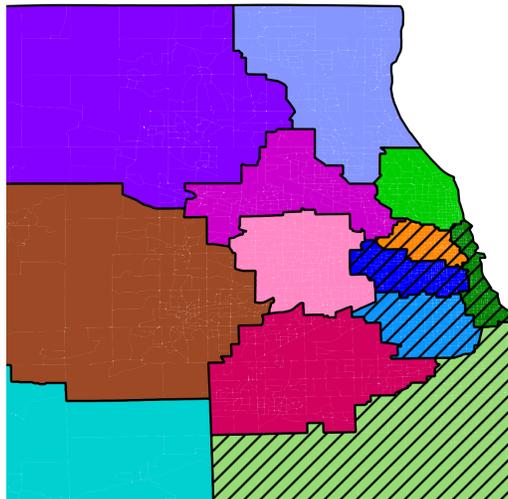


(b) The Chicago area

Figure 11 A congressional plan optimized for Partisan Asymmetry (PA2), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

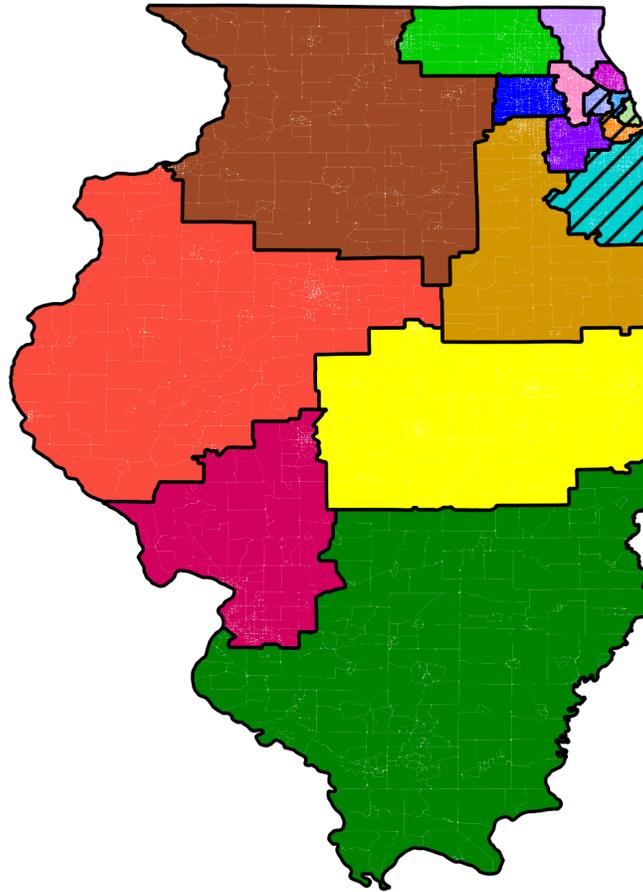


(a) CMPTTV1

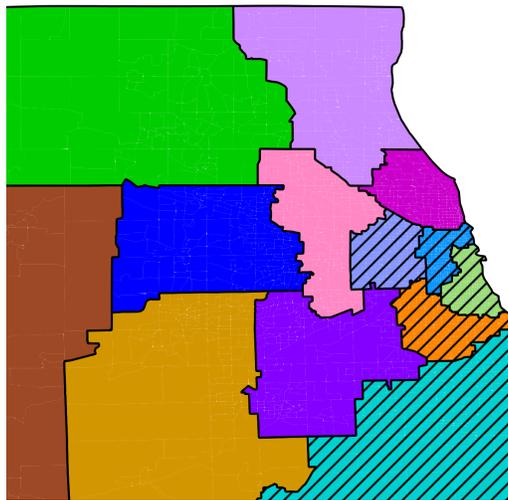


(b) The Chicago area

Figure 12 A congressional plan optimized for competitiveness (CMPTTV1), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.



(a) CMPTTV2



(b) The Chicago area

Figure 13 A congressional plan optimized for competitiveness (CMPTTV2), with a closer view of the Chicago area. District boundaries are shown in black and majority-minority districts are hatched with black stripes.

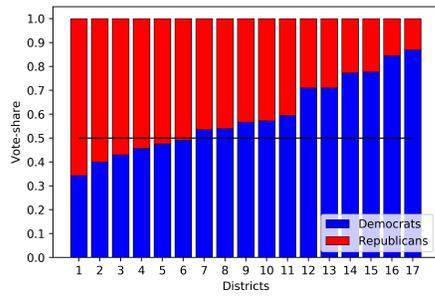
6. Discussion

This section reports the metric values for each plan, examines the trade-offs between plans, and discusses the fairness metric values that are achievable for Illinois given its voter distribution and redistricting requirements.

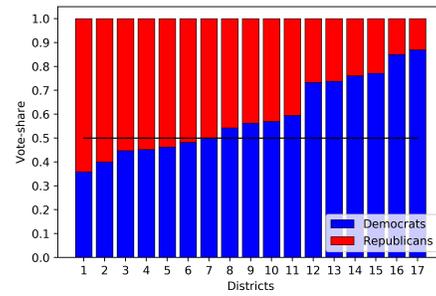
Plan	Comp	EG	PA	Cmpttv	D/R
COMP1	5,435	3.99%	0.038	5	11/6
COMP2	5,618	9.88%	0.047	5	10/7
EG1	5,550	1.5%	0.045	3	12/5
EG2	5,559	1.5%	0.043	3	12/5
PA1	5,987	3.94%	0.015	2	11/6
PA2	6,094	4.63%	0.010	2	11/6
CMPTTV1	5,397	3.99%	0.046	6	11/6
CMPTTV2	5,674	3.90%	0.052	8	11/6
2021 Plan	11,722	13.57%	0.057	3	14/3

Table 1 The metric values for the congressional district plans. From left to right, the table lists each plan's compactness (Comp), Efficiency Gap (EG), Partisan Asymmetry (PA), the number of seats within a 10% margin of victory (Cmpttv), and the number of Democratic and Republican seats (D/R).

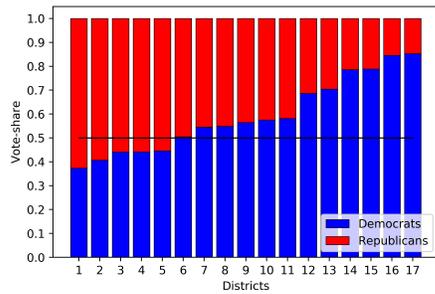
The COMP1/2 plans in Section 5.1 prioritize compactness, hence they are the most visually appealing district plans in this report. However, it is also important to examine how solely prioritizing compactness affects the partisan characteristics of these district plans. Table 1 shows that COMP1/2 have mediocre Partisan Asymmetry values, and five competitive seats each. COMP1 has a better Efficiency Gap value than COMP2 (3.99% compared with 9.88%). Figures 14a and 14b show that Democrats are expected to narrowly win a competitive district in COMP1 that they narrowly lose in COMP2; this improves the Efficiency Gap value, since Democrats waste fewer votes by narrowly winning this district. Both COMP1 and COMP2 have mediocre Partisan Asymmetry values (0.038 and 0.047, respectively); slight asymmetry is evident in Figures 14a and 14b. Most Democratic voters are heavily concentrated in the Chicago area, so urban districts are packed with Democrats. Maintaining the five majority-minority districts may also contribute to the packing of Democrats in plans optimized for compactness, since these districts are largely located in areas with high concentrations of Democratic voters. Although the partisan



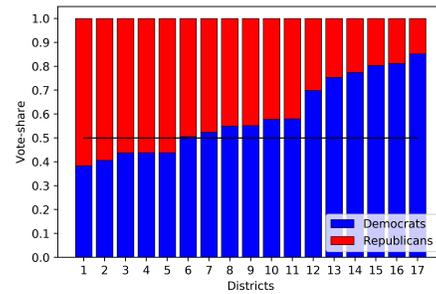
(a) Vote-shares for COMP1



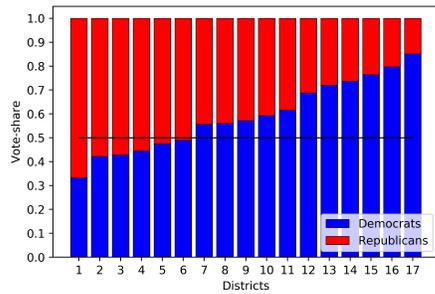
(b) Vote-shares for COMP2



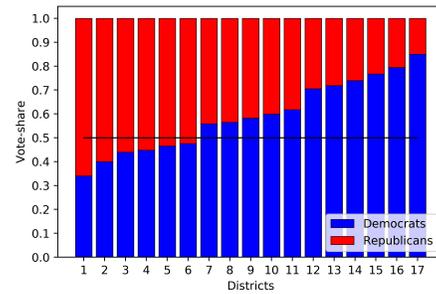
(c) Vote-shares for EG1



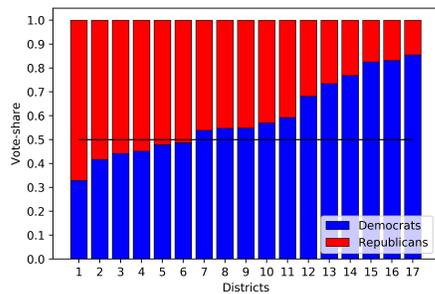
(d) Vote-shares for EG2



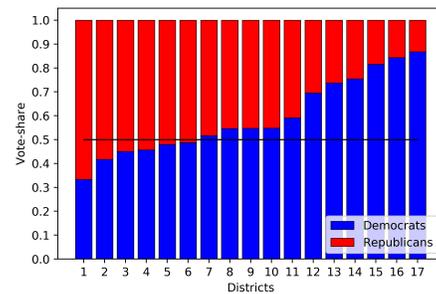
(e) Vote-shares for PA1



(f) Vote-shares for PA2



(g) Vote-shares for CMPTTV1



(h) Vote-shares for CMPTTV2

Figure 14 The estimated fraction of votes won by Democrats/Republicans in each district for the congressional plans (based on past election results). Democratic fractions are shown on the bottom in blue and Republican fractions are shown on the top in red.

fairness values for COMP1/2 show room for improvement, they are better than the partisan fairness values for the new 2021 plan (Table 1).

Next, we examine the additional plans from Section 5.2 that prioritize the Efficiency Gap. COMP1 already has a decent Efficiency Gap value, but EG1/2 illustrate that the Efficiency Gap can be improved further, while maintaining reasonable district shapes. For example, Table 1 shows that EG1/2 have compactness scores comparable to COMP1/2, but both have Efficiency Gap values of 1.5%. Hence, Democrats and Republicans waste votes more equally in EG1/2 than in COMP1/2, but the districts are similarly compact.

For the Partisan Asymmetry plans from Section 5.3, Table 1 shows that the Partisan Asymmetry values for PA1/2 are better than COMP1/2 (0.015 and 0.010 compared with 0.038 and 0.047). As discussed in Section 5.3, PA1/2 have more irregular district shapes than COMP1/2; the compactness scores for PA1/2 are the worst among all plans in this report. However, both plans have significantly better compactness scores than the new 2021 plan (5,987 and 6,094 compared with 11,722). The district shapes in PA1/2 are not extremely convoluted; both plans have a few tendrils in the Chicago area (Figures 10b and 11b) or long central districts (Figure 11a). As mentioned in Section 5.3, these irregular shapes may be a result of maintaining majority-minority districts in addition to redistributing Democratic voters. Figures 14e and 14f shows that the Democratic voters in PA1/2 are more symmetrically distributed throughout the districts than in COMP1/2 (Figures 14a and 14b). Hence, there is a slight trade-off between compact district shapes and excellent Partisan Asymmetry values.

As with EG1/2, CMPTTV1/2 from Section 5.4 have compactness scores comparable to COMP1/2. However, Table 1 shows that CMPTTV1 has one more competitive seat than COMP1/2 and CMPTTV2 has three more. Also note that CMPTTV1/2 have 3-6 more competitive seats than EG1/2 and PA1/2. Figures 14g and 14h show that Democrats and Republicans are expected to win three competitive districts each in CMPTTV1 and four competitive districts each in CMPTTV2. Hence, these competitive plans do not crack either party. This is evident in the Efficiency Gap values of CMPTTV1/2 in Table 1; both plans have reasonable Efficiency Gap values below 4%.

From the compact, Efficiency Gap, Partisan Asymmetry, and competitive plans, we conclude there are multiple options for Illinois congressional district plans to improve partisan fairness while satisfying constitutional requirements and maintaining compactness.

Illinois’s political geography, combined with maintaining five majority-minority districts, can cause plans optimized for compactness to pack Democratic voters in urban districts; however, excellent Efficiency Gap values and more competitive districts can be achieved without sacrificing compactness. Partisan Asymmetry can be significantly improved as well, but this improvement tends to require more elongated district shapes. Overall, congressional district plans with small Efficiency Gap/Partisan Asymmetry values or several competitive districts would strike a balance between partisan fairness, compactness, and constitutional requirements.

6.1. Limitations

The district plans constructed for this report provide insight into how political geography, maintaining majority-minority districts, and losing a congressional seat can impact Illinois congressional redistricting. However, there are some limitations related to the data used to construct the plans; these limitations impact the optimization algorithm’s ability to fully consider all possible district plans. Once these limitations are considered, the eight congressional plans in this report could serve as viable plans for Illinois.

As mentioned in Section 4.1, we construct district plans with counties and census tracts, rather than census blocks. Although we enforce a strict population balance requirement, single-person population balance is not achieved. Therefore, the district plans in this report would require manual adjustment to achieve single-person population balance. Additionally, constructing the plans with blocks could provide more district plan options. We also distribute precinct-level election data proportionally to census blocks/tracts; this assumes that Democratic and Republican voters are spread evenly throughout the voting precincts, which might not be the case.

Appendix A: Additional Technical Details

In this appendix we discuss some of the technical details for creating district plans with the optimization algorithm. As mentioned in Section 3, the algorithm we use is based on a method from DeFord et al. (2019). Their paper fully explains the mechanics behind how to alter the boundary between two districts in each step of the algorithm. While their goal is to create a large sample of legal district plans for statistical analysis, our goal is to iteratively find better and better plans (with respect to some fairness metric) until there is no opportunity for significant improvement.

All experiments are run on a 3.10 GHz Core i5 2400-CPU machine with 8 GB of RAM. The algorithm steps from Section 3 are applied in multiple phases; these phases are distinguished by the initial plan the algorithm uses, the metric the algorithm improves, and the redistricting constraints the algorithm enforces. Note that the basic steps of the algorithm from Section 3 do not change between phases. Figure 15 outlines these phases and the rest of this appendix provides additional details.



Figure 15 A flowchart for the optimization algorithm phases used to construct district plans. The algorithm first optimizes population balance and creates majority-minority districts, then can proceed to optimize a particular fairness metric.

To create the congressional district plans, we begin with a randomly generated contiguous plan. This contiguous plan is generated by first dividing the entire state into two contiguous districts, then recursively dividing the most populated district in two until 17 districts are obtained (DeFord et al. 2019). Next, we optimize this plan for population balance (this is Phase 1 in Figure 15); the algorithm transitions between contiguous plans with smaller and smaller population deviations until 1% population balance is satisfied (we use a looser population balance requirement in this stage for computational efficiency). The algorithm alternates between two methods to choose which two districts to modify during an iteration. For the first method, the algorithm first chooses the district with the largest population deviation, then chooses a random neighboring district. For the second method, the algorithm first chooses a district at random, then chooses a random neighboring district. We alternate between these methods to prevent the algorithm from getting stuck in a local minimum; improving population balance throughout the state creates more opportunities to shift population to/from the district with the largest population deviation. Achieving population balance takes roughly 200 iterations (approximately two hours).

We initially collect three plans that satisfy population balance; these plans are analyzed with demographic data to determine how many majority-minority districts they contain. The plan that is closest to containing five majority-minority districts is manually adjusted until five majority-minority districts are achieved (this is Phase 2 in Figure 15). We optimize this modified plan for population balance again (since manual adjustment disrupts population balance) and collect two new plans that a) satisfy 0.5% population balance, and b) have five majority-minority districts (this is Phase 3 in Figure 15). These two plans serve as initial plans for the remaining experiments.

First, we optimize plans solely for compactness (this is the appropriate Phase 4 in Figure 15). The algorithm begins with the population-balanced plans, then transitions between contiguous, population-balanced plans with better and better compactness scores until the scores appear to plateau. For these plans, and for the remaining experiments, the algorithm chooses which two districts to modify at each iteration in the following manner. First, the districts are listed in a random order. At each iteration, the algorithm chooses the next district in this list, then chooses a random neighboring district. When the algorithm has completed enough iterations to finish the list (i.e., has completed a *cycle*), a new list of districts is created, in a new random order. Cycling through the districts ensures that all areas of the state are changing at the same pace. Improving compactness takes roughly 50-150 cycles (approximately 12-22 hours).

Next, we optimize plans for the Efficiency Gap (this is the appropriate Phase 4 in Figure 15). The algorithm begins with the population-balanced plans, then transitions between contiguous, population-balanced plans that gradually improve the Efficiency Gap. The algorithm is run until the Efficiency Gap falls below a certain threshold; we use a threshold of 1.5%. Once the threshold is achieved, the algorithm optimizes the plans for compactness, while maintaining an Efficiency Gap value below the threshold (this is the appropriate Phase 5 in Figure 15). Improving the Efficiency Gap takes roughly 30 cycles (approximately 3 hours), then improving compactness takes roughly 70 cycles (approximately 16 hours). We optimize plans for Partisan Asymmetry in the same manner described for the Efficiency Gap (using the appropriate Phases 4 and 5 in Figure 15); the thresholds we use for Partisan Asymmetry are 0.01 and 0.015. Improving Partisan Asymmetry takes roughly

50 cycles (approximately 12 hours), then improving compactness takes roughly 150 cycles (approximately 40 hours).

Lastly, we optimize plans for competitiveness (this is the appropriate Phase 4 in Figure 15). In contrast to the Efficiency Gap and Partisan Asymmetry plans, we improve competitiveness and compactness simultaneously. The algorithm begins with the population-balanced plans, then transitions between contiguous, population-balanced plans with better and better compactness scores. However, if the algorithm creates a competitive district during an iteration, that district is required to remain competitive for all future iterations. Therefore, as compactness improves, the number of competitive districts also increases. Improving competitiveness and compactness simultaneously takes roughly 70-110 cycles (approximately 16-26 hours).

References

- Ballotpedia (2015) Redistricting in Illinois. URL https://ballotpedia.org/Redistricting_in_Illinois, (Date accessed: 2021-10-15).
- DeFord D, Duchin M, Solomon J (2019) Recombination: A family of Markov chains for redistricting. *arXiv preprint, arXiv:1911.05725* .
- Griffith EC (1907) *The Rise and Development of the Gerrymander* (Chicago: Scott, Foresman and Co.).
- Grofman B (1983) Measures of bias and proportionality in seats-votes relationships. *Political Methodology* 9(3):295–327.
- Grofman B, King G (2007) The future of partisan symmetry as a judicial test for partisan gerrymandering after LULAC v. Perry. *Election Law Journal* 6(1):2–35.
- Hirano S, Snyder J (2012) Primary elections and political accountability: What happens to incumbents in scandals? *Quarterly Journal of Political Science* 7(4):447–456.
- Illinois House Democrats (2021) Illinois redistricting. URL <https://ilhousedems.com/redistricting/>, (Date accessed: 2021-10-29).
- McCarty N, Poole KT, Rosenthal H (2009) Does gerrymandering cause polarization? *American Journal of Political Science* 53(3):666–680.
- National Conference of State Legislatures (2021) Redistricting criteria. URL <https://www.ncsl.org/research/redistricting/redistricting-criteria.aspx>, (Date accessed: 2021-09-01).
- Stephanopoulos N, McGhee E (2015) Partisan gerrymandering and the efficiency gap. *The University of Chicago Law Review* 82(2):831–900.
- Tapp K (2018) Measuring political gerrymandering. *arXiv preprint, arXiv:1801.02541v2* 1–22.
- US Census Bureau (2020a) Hispanic or Latino, and not Hispanic or Latino by race. URL <https://data.census.gov/cedsci/table?q=&g=0400000US17\%24100000&y=2020&tid=DECENNIALPL2020.P2>, (Date accessed: 2021-09-16).
- US Census Bureau (2020b) Race. URL <https://data.census.gov/cedsci/table?q=&g=0400000US17\%24100000&y=2020&tid=DECENNIALPL2020.P1>, (Date accessed: 2021-09-16).
- US Census Bureau (2020c) Tiger/line shapefiles. URL <https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.2020.html>, (Date accessed: 2021-09-16).
- Voting and Election Science Team (2021) Voting and Election Science Team. URL <https://dataverse.harvard.edu/dataverse/electionscience/?q=illinois>, (Date accessed: 2021-10-07).
- Young H (1988) Measuring the compactness of legislative districts. *Legislative Studies Quarterly* 13(1):105–115.