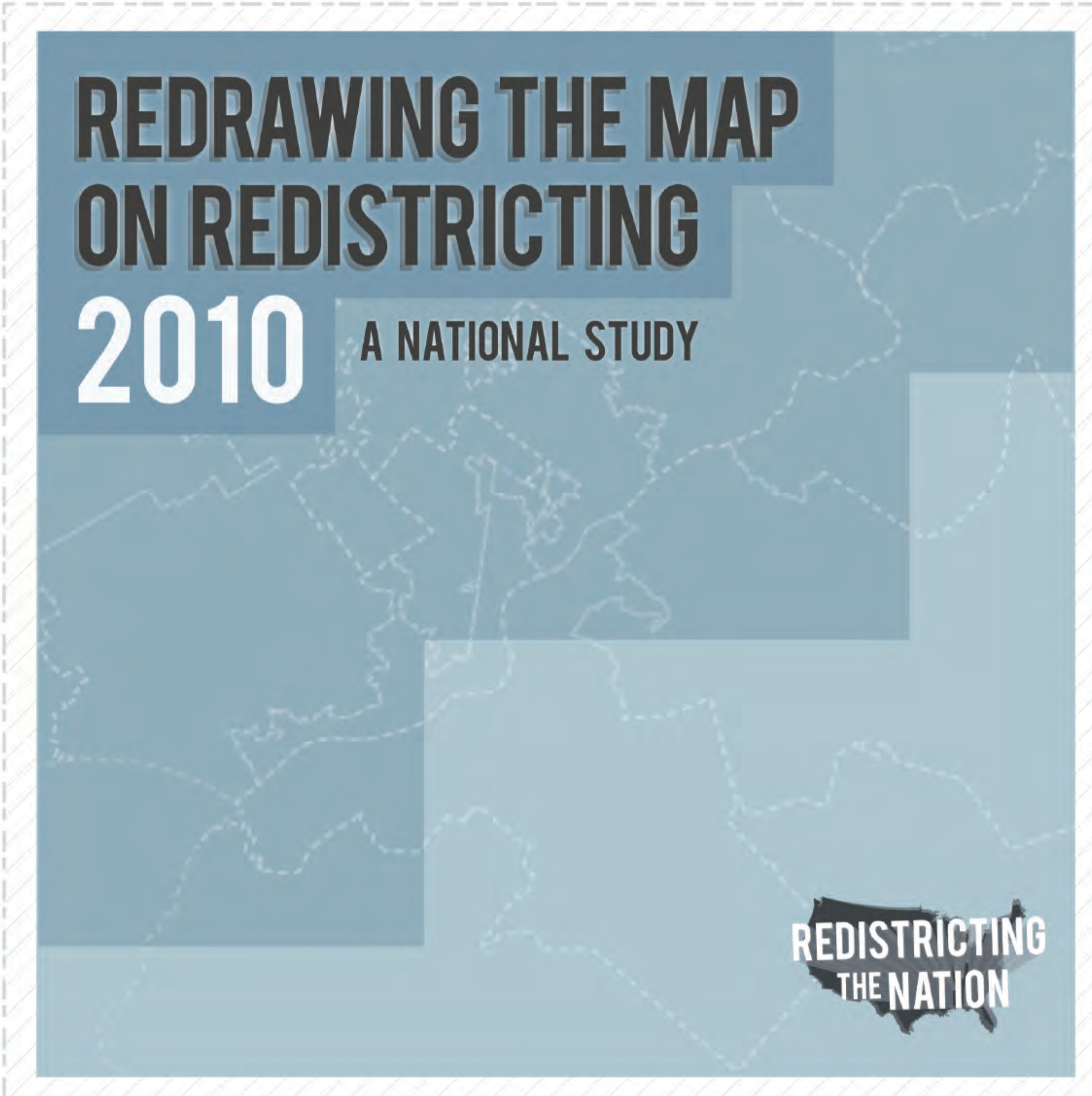

azavea cicero

Using geospatial analysis to measure electoral district compactness and limit gerrymandering

An Azavea White Paper

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Introduction

The historically high voter turnout in the U.S. general election in November 2008 was heralded as a resurgence of democratic ideals. The 2010 U.S. Census and subsequent redistricting offer an opportunity to carry this renewed political engagement forward into lasting electoral change. In 2006, the turnout for the midterm Congressional elections was the highest in a decade and Democrats defeated twenty-two Republican incumbents and won eight open Republican-held seats in the U.S. Congress. While this was a dramatic shift in political power compared to years like 2002, when just four seats switched parties, the results nevertheless represented an election system in which 94% of incumbents won their races.

There are many factors contributing to electoral ills, but one of them, gerrymandering—the practice of crafting district boundaries for political gain—appears to be getting worse. Recent battles in Texas, California, Georgia and New York have highlighted the increasing sophistication with which the political parties carry out the practice. In Texas, after Republican House Majority Leader Tom DeLay led a 2003 effort to gerrymander the previously approved 2002 districts, Democratic legislators fled to Oklahoma and New Mexico in an attempt to prevent a legislative quorum. The Republican gerrymander was seen as payback for the Democrats gerrymandering of the districts after the 1990 census. The plan was approved, but led to a Supreme Court challenge. In its June 2006 decision, the Supreme Court validated the Texas redistricting. The 7-to-2 decision allows redrawing of districts to occur as often as a state chooses, so long as it does not harm minorities by violating the 1965 Voting Rights Act. In New York, Republicans in the northern part of the state maintain a perpetual majority in the State Senate by incorporating large prison populations located there when determining population, but with the clear understanding that the prison inmates will not be able to vote. In Georgia, Republicans took control of the state government in 2004 and promptly re-drew the previous Democratic gerrymander.[1] Democrats have been accused of doing the same in Maryland in 2002.

Gerrymandering affects election outcomes in a number of ways:

- *Reduces Electoral Competition* – gerrymandering creates larger margins of victory and enables the creation of 'safe seats'.
- *Reduces Voter Turnout* – as the chance of affecting the outcome of an election is diminished, the number of voters is reduced and campaigns have few incentives to increase turnout.
- *Outcomes Determined in Primaries* – since many seats are decided in the party primary election, only registered party members receive a meaningful vote. This can also indirectly lead to a more partisan political dialogue—if there are more contests decided in the primaries, partisan stances on a range of issues will tend to dominate since party members are effectively the only voters.
- *Increases Incumbent Advantage* – incumbents are often both engineering the gerrymandering and are the beneficiaries of it.
- *Increases Election Costs* – sprawling gerrymandered districts make it harder for candidates—and challengers in particular—to build name recognition through grassroots, door-to-door canvassing, forcing candidates to make expensive media buys to build up name recognition.

So we know gerrymandering happens and we know some of its effects. Why would Azavea, a software development firm, research this topic? In 2005 Azavea began developing a software service that would enable some local Philadelphia nonprofits to match their member addresses with the local council person representing the address in order to support political advocacy efforts. As we expanded the service beyond Philadelphia to more than 50 cities across the United States, we also began looking at federal and state legislative districts and were struck by some of the tortuous shapes created by gerrymandering processes at all levels of government. We began to wonder if it would be possible to generate a top-ten list of "most gerrymandered districts". A 2006 white paper was the outcome of that curiosity.

This paper is a revision to that original white paper. So why revise it now? In the three years since we produced the initial version of the white paper, Azavea's engagement with election-related issues has continued to grow. We decided to expand the white paper at this time for several reasons. First, and perhaps most importantly, the 2010 decennial census is imminent and redistricting at all legislative levels will follow shortly thereafter. If the districts that are drawn this time are to be any improvement, we must act now.

Second, in the past few years there has been a growing movement nationwide in support of transparency and open government, at every legislative level. In many cities and states, legislative redistricting has long been conducted in relative secrecy by the very legislators who stand to benefit from the boundaries they draw.

Finally, we recognized that the spread of personal computers and the rise of the internet have made both hardware and software increasingly accessible to the general public. We were curious about the role that technology can play in the redistricting process. In the previous edition of the white paper we asked whether gerrymandering was getting worse. For this version we have refocused our energies, asking instead what can be done to improve the problem, and how spatial analysis technologies in particular can be used to serve the public interest. Many claims have been made about the role of GIS in redistricting, running the gamut from charges that geographic information technologies enable more sophisticated gerrymandering to the optimistic assertion that we should "let a computer do it". Whether employed by back room dealers or conceived of as an algorithmic panacea, this is a notion of GIS as opaque. Instead, we believe that GIS is a tool in the redistricting process, the full utility of which can be only realized as part of a public process.

For these reasons, our research questions are slightly different than they were in the first gerrymandering white paper:

How do we measure it? What are some of the most commonly used methods of quantifying compactness and what are their strengths and limitations? How have these methods been translated into law and practice?

Where are worst examples? We know we have some local council districts in Philadelphia (where Azavea is headquartered) that are pretty gerrymandered, but how does this compare to other cities?

What are the best practices for improving the process? Azavea develops web-based software that uses geospatial technology for crime analysis, real estate, government administration, social services and land conservation. But the recent use of these tools to subvert the electoral process demonstrates one way in which the same technologies can be used to harm our society. Are there ways in which these technologies can be used to increase transparency and civic engagement?

This white paper will focus on a practical assessment of compactness and will discuss some of the strengths and shortcomings of various measures. For this reason, the methodology of this white paper has been expanded from a single compactness measure to four different compactness measures, which each capture a different geometric concept. The Gerrymandering Index that we developed in the first edition of this white paper is still employed to evaluate the compactness of local districts, but we have elected to use raw scores for federal and state districts because these are what have been mandated by most statutes and legislation that define compactness. We have also expanded our data set substantially by incorporating new cities into our local district analysis and by adding state legislative districts to the federal and local districts included in our original analyses. Theses changes in the data and methodology mean that the Top Five and Top Ten lists we have generated in this version of the white paper differ in significant ways from those in the 2006 publication.

More on Gerrymandering

The term gerrymandering was coined in 1812 by political opponents of then-governor Elbridge Gerry in response to controversial redistricting carried out in Massachusetts by the Democratic–Republicans. The word is a portmanteau of Gerry's name with the word salamander, a creature that one newly-created district was said to resemble. The term gerrymandering is now widely used to describe redistricting that is carried out for political gain, though it can be applied to any situation in which distortion of boundaries is used for some purpose.

Figure 1: 1812 political cartoon run in the Boston Weekly Messenger depicting the salamander-like district that inspired the term gerrymandering

So how does it work? There are two primary strategies employed in a gerrymander: "packing" and "cracking". *Packing* refers to the process of placing as many voters of one type into a single district in order by reduce their effect in other, adjacent districts. If one party can put a large amount of the opposition into a single district, they sacrifice that district, but make their supporters stronger in the nearby districts. The second technique, *cracking*, spreads the opposition amongst several districts in order to limit its effect. These techniques are obviously most effective when they are combined. In both cases, the goal is to create wasted votes for the opposition. Voters in the opposition party that are packed into one district will always be sure of winning that district (so the votes are wasted there), while they will be guaranteed to lose other seats (again, wasting their votes). The overall objective is to maximize the number of wasted votes for the opposition.

The opportunity to conduct gerrymandering arises from the constitutional requirement to re-apportion Congressional representation based on the decennial census. The U.S. Constitution does not specify how the redistricting should occur, however, and each state is free to determine the methodology. All states have a 'contiguity rule' requiring that districts be contiguous land areas. Some states—Arizona, Hawaii, Idaho, Montana, New Jersey and Washington—mitigate the problem by requiring that the line-drawing be carried by out non-partisan commissions. But most states do not do this, and the reasons are obvious—gerrymandering tends to protect the seats of those in power.

While congressional districts have received the most media attention, gerrymandering can be seen in state assembly and city council districts as well. We can also observe a sort of "tax base gerrymandering" that can occur when a municipal government annexes a nearby community by running the municipal boundary along a highway or river in order to capture the higher tax base of an outlying suburb. Houston is an example of where this has occurred. And while the United States is one of the only western democracies that does not systematically limit the practice, accusations of gerrymandering have been leveled in Singapore, Canada, Germany, Chile, and Malaysia.

There is some hope for reform. Good government advocates have become increasingly vocal about gerrymandering, and, since the last edition of this white paper was published, California voters passed Proposition 11, a referendum establishing an independent redistricting commission. Inspired by a redistricting contest run by the state of Ohio, an Illinois State Representative has proposed legislation to open the redistricting process up to public submissions. At the federal level The

Fairness and Independence in Redistricting Act (H.R. 3025 & S. 1332) would prohibit states from carrying out more than one Congressional redistricting after a decennial census and would require states to conduct redistricting through a public, bipartisan commission.

Cicero

Gerrymandered districts are often identifiable by their torturous and obscure shapes. Thus one means of measuring the extent of gerrymandering in a district is to calculate its 'compactness'; the more compact its shape, the less likely it is to have been gerrymandered. Azavea has used this measurement and information on local, state and federal districts assembled from our Cicero legislative boundary and elected official database to measure district compactness and, in the case of local districts, to create a Gerrymandering Index.

Azavea developed the Cicero Legislative District and Elected Official Web API ("application programming interface") in 2005 as a cost effective and accurate way to match citizens, businesses and other organizations with their local elected officials. Cicero was designed to enable local governments, non-profit organizations and political organizations to empower their citizens and members to engage with elected officials and thereby influence the outcome of decisions. It has the ability to place voters into legislative districts on local, state and federal levels based on address information. It also provides maps of legislative districts and provides information about elected officials, including contact information and committee assignments.

The backbone of Cicero's functionality is a geographic database for local and state legislative districts. There is no official repository of spatial data on local districts—Azavea obtained the local information for each city individually, through local government websites where possible and directly from municipal officials when necessary. Thus Cicero is now the leading sources of spatial information on local city and county council districts, currently containing comprehensive data for more than 80 of the largest U.S. cities. It was this large collection of data that enabled Azavea to investigate gerrymandering on such a wide scale. The Congressional district boundaries for the 111th were derived from those published for each congress by the Department of Commerce, Census Bureau, Geography Division, and the state assembly and senate districts were assembled from state spatial data clearinghouses or from the U.S. Census Bureau.

Compactness

Background

Academic articles, state laws and Supreme Court rulings have all cited compactness, along with contiguity, as a traditional districting principle, and low compactness is considered a sign of a potential gerrymander. Unfortunately, the legal standard for compactness has been similar to Justice Stewart's famous definition of obscenity: I know it when I see it.

Some proponents of redistricting reform, most prominently Daniel D. Polsby and Robert D. Popper, have advocated strongly for the use of quantitative compactness standards as an evaluative tool in the redistricting process[2]. While Polsby and Popper have lent their names to a particular compactness measure (discussed below), they argue that the establishment of *any* compactness standard is preferable to none. Others have questioned the utility of such thresholds, and research indicates that the extent to which various compactness measures agree with one another is highly inconsistent.[3] Because each measure of compactness captures a slightly different geometric or geographical phenomenon, it is a somewhat arbitrary choice to select a particular compactness metric as the means of accepting or rejecting a single district boundary.

That said, a low quantitative compactness score does serve as a useful indicator that a particular district shape is irregular. There are also meaningful ways to judge whether any given compactness measure captures district geography in a consistent manner. In particular, the compactness score of a district should not change if the shape is scaled (made larger or smaller), translated (moved to a different location), or rotated. Although mathematicians and geographers have devised countless ways for quantifying compactness, given the data and tools we had at hand, we were constrained to using geometric measures of compactness—using the shape of the polygon formed by the boundaries of the district—rather than those based on population weights. In the 2006 edition of this white paper we used just one measure of compactness, adapted as an index, but here we have expanded our analysis to include four measures of compactness that both perform consistently and are in relatively common use in practice.

Types of Measures

Most compactness measures attempt to quantify the geometric shape of a district relative to a perfectly compact shape, often a circle. The compactness measures we have selected can be divided into two categories: those that measure dispersion and those that measure indentation.

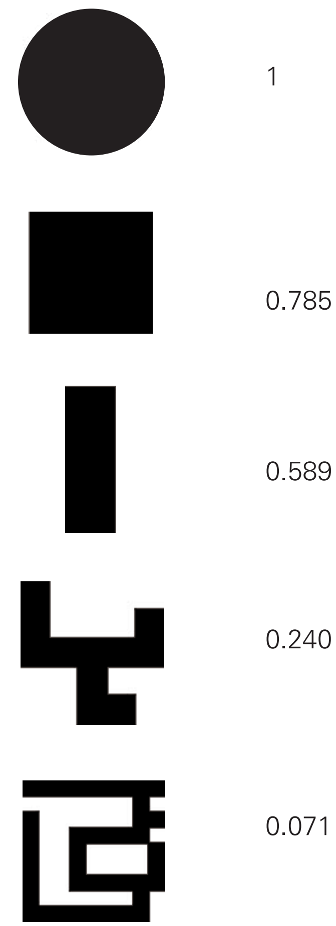
Dispersion-based measures evaluate the extent to which the shape of a district is dispersed, or spread out, from its center. Geometrically, these are area-based measures, comparing the area of the district to the area of an ideal form. For instance, an ellipse is more dispersed than a circle and is therefore less compact.

Other measures evaluate district compactness based on indentation: how smooth (better) or contorted (worse) the boundaries of a district are. Indentation can be measured by simply summing the total length of the district boundaries or by using the perimeter of a district as part of a perimeter-area ratio.

For instance, the Polsby-Popper method calculates the compactness (C) of a given polygon as 4π times the area (a) divided by the perimeter (p) squared ($C = 4\pi a/p^2$), providing a measure between 0 and 1. Using this ratio, a truly compact shape (a circle) would score a 1. **Figure 2** illustrates the compactness scores for several shapes, using the Polsby-Popper perimeter-area ratio.

All four of the compactness measures we have applied score district compactness in a similar manner. We have multiplied all of the scores by 100, meaning that the most compact districts score close to 100 and the least compact approach 0.

Figure 2: Shape and Compactness Score ($C = 4pa/p^2$)



Reock

One of the first and most conceptually simple measures of a district's compactness was proposed by political scientist E.C. Reock and takes its name from him.[4] His method consists of comparing the area of the district to the area of the minimum spanning circle that can enclose the district (**Figure 3**).

The Reock method is relatively easy to visualize, but has a few practical shortcomings. Most redistricting statutes mandate that legislative districts be contiguous, but in coastal areas islands must be included. The inclusion of islands in the minimum spanning circle necessarily increases its size, often dramatically. As the area of the minimum spanning circle increases while the district area remains the same, the compactness score decreases correspondingly, but is unrelated to gerrymandering (**Figure 4**).

To circumvent this problem, we calculated the minimum spanning circle for each part of the district independently (**Figure 5**). In this case, the Reock score of the district represents the total area of the district divided by the summed areas of these individual minimum spanning circles.

The Reock measure is also notable in that it consistently rates districts of a particular shape as least compact, as **Table 1** demonstrates. The districts judged least compact by the Reock measure are those whose shape is long and thin. It is easy to understand why this should be the case geomentrically: long thin districts quickly increase the diameter, and thus the area, of the minimum spanning circle while adding little area to the district itself, thus skewing the ratio. In this way we can see that the Reock measure's definition of compactness is strongly related to dispersion.

Figure 3: Reock compactness measure: multiple minimum spanning circles drawn, one for each distinct part of the district

Figure 4: Reock: ratio of the district area (solid blue) to the area of the minimum spanning circle (orange hatches)

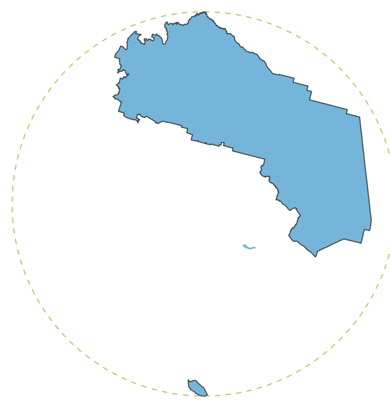


Figure 5: Reock compactness measure: single minimum spanning circle drawn to include all parts of the district

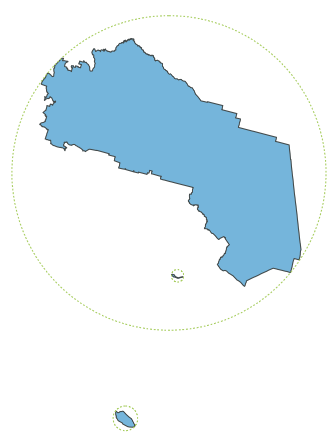
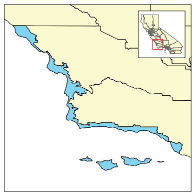
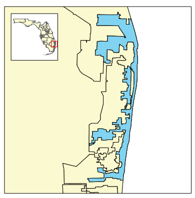


Table 1: Top Five least compact congressional districts, calculated using the Reock measure

1. California–District 23
Compactness Score: 4.65

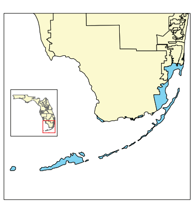


2. Florida–District 22
Compactness Score: 8.30



3. New York–District 8
Compactness Score: 9.24

4. Florida–District 18
Compactness Score: 10.07



5. New York–District 28
Compactness Score:11.28

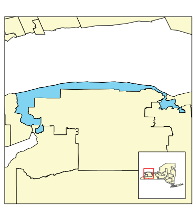
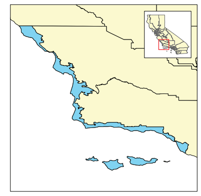
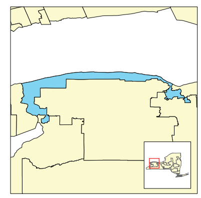


Table 2: Top Five least compact congressional districts, calculated using the Convex Hull measure

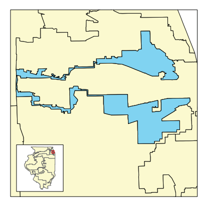
1. California–District 23
Compactness Score: 22.58



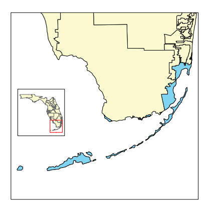
2. New York–District 28
Compactness Score: 27.38



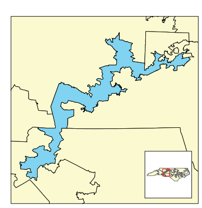
3. Illinois–District 4
Compactness Score: 32.77



4. Florida–District 22
Compactness Score: 33.55



5. North Carolina–District 12
Compactness Score 34.79



Convex Hull

The convex hull compactness measure is quite similar to the Reock measure and for this reason suffers some of the same shortcomings. As its name indicates, the convex hull measure represents the ratio of the district area to the area of the minimum convex bounding polygon (also known as a convex hull) enclosing the district.[5] Perhaps the easiest way to conceptualize a convex hull is to imagine the polygon that would result if you were to stretch a rubber band around a shape (**Figure 6**).

Like the Reock measure, the compactness score of a coastal district is depressed by the inclusion of islands. The methodological solution to this problem is the same: determine the convex hulls for each part of the district independently, and calculate the district compactness score by dividing the total district area by the summed area of the distinct convex hulls.

Unlike the circumcircle of the Reock measure, the shape of the convex hull adapts to the particular boundaries of the district. For this reason, the convex hull measure is essentially capturing the extent to which the boundaries of the district bypass some geographical areas to capture others. Because the convex hull measure relies on a convex polygon as its point of comparison, shapes with substantial concave areas—C or S shapes—will earn low compactness scores (see **Table 2**). That said, the convex hull measure is still primarily a measure of dispersion, being more sensitive to the overall shape of the district than to minute variations of the boundaries.

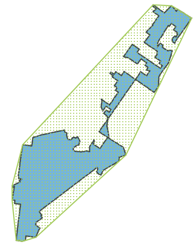


Figure 6: Convex Hull: ratio of the district area (solid blue) to the area of the minimum bounding convex polygon (green stipple)

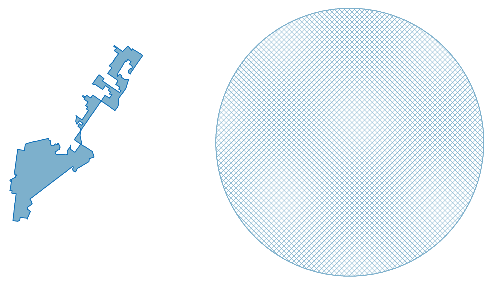


Figure 7: Polsby-Popper: ratio of the district area (solid) to the area of a circle with the same perimeter (cross hatches)

Figure 8: Schwartzberg: ratio of the perimeter of the district (solid line) to perimeter of a circle of equal area (dashed line)

Polsby-Popper and Schwartzberg

Polsby-Popper is perhaps the most common measure of compactness. It represents the ratio of the area of a district to the area of a circle with the same perimeter (**Figure 7**). We used this perimeter-area measure as the basis for the Gerrymandering Index presented in our 2006 white paper. The inputs for this compactness measure are simple area and perimeter values, making the calculations easy and quick to perform.

In this analysis, we included an additional perimeter-area measure of compactness, Schwartzberg. Schwartzberg is the ratio of the perimeter of a district to the perimeter of a circle with equal area (**Figure 8**).

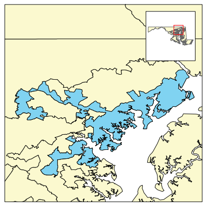
Both of these measures evaluate district compactness based on indentation—how smooth or contorted the boundaries of a district are. In this way, perimeter-area measures are very sensitive to small changes in district boundaries; districts that have detailed coastal boundaries are likely to be assigned low compactness scores, even if the overall shape of the district is reasonably compact. The Polsby-Popper and Schwartzberg measures tend to place too much emphasis on the perimeter of the district and not enough on the overall shape of the district.

TheTop Five least compact congressional districts captured by the Polsby-Popper and Schwartzberg measures are presented in **Table 3**. For the sake of clarity, we inverted the Schwartzberg scores so that all compactness scores fall between 0 (least compact) and 100 (most compact).

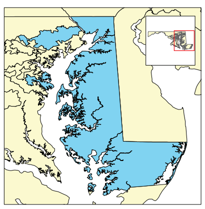
Table 3: Top Five least compact congressional districts, calculated using the Polsby-Popper and Schwartzberg measures

Poslby-Popper

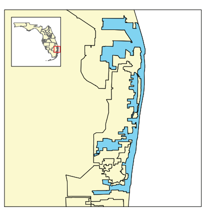
1. Maryland–District 2
Compactness Score: 20.37



2. Maryland–District 1
Compactness Score: 20.87

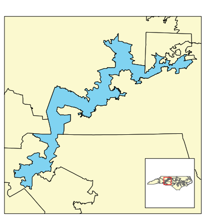


3. Florida–District 22
Compactness Score: 26.63



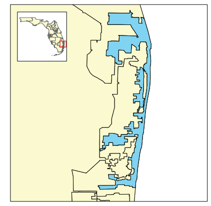
4. Maryland–District 5
Compactness Score: 27.61

5. North Carolina–District 12
Compactness Score: 34.87

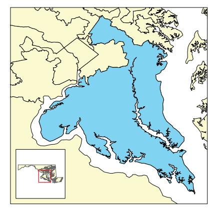


Schwartzberg

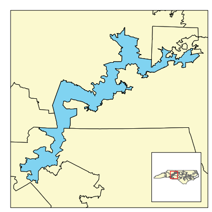
1. Florida–District 22
Compactness Score: 16.32



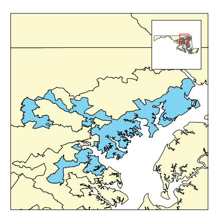
2. Maryland–District 5
Compactness Score: 17.12



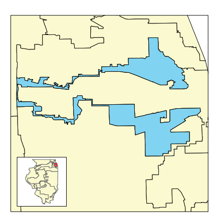
3. North Carolina–District 12
Compactness Score: 18.67



4. Maryland–District 2
Compactness Score: 18.82



5. Illinois–District 4
Compactness Score: 19.41



Redistricting at the local level

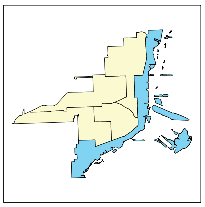
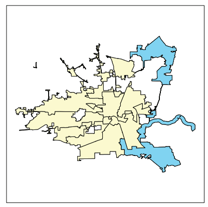
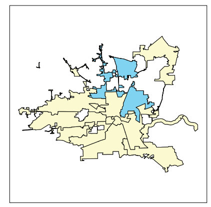
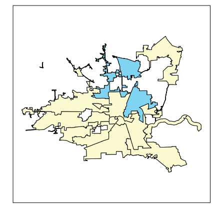
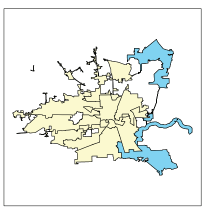
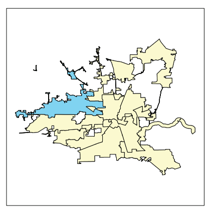
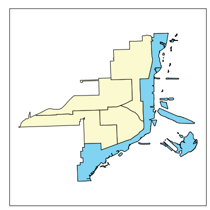
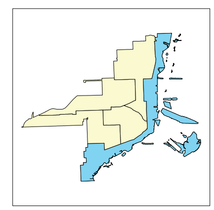
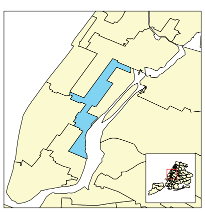
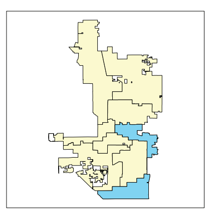
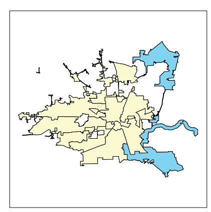
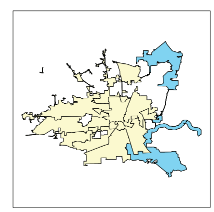
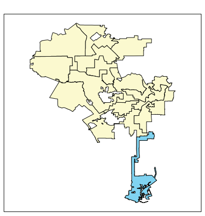
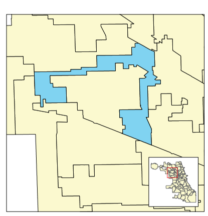
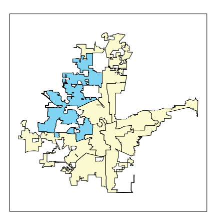
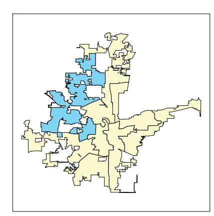
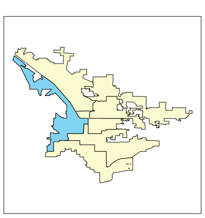
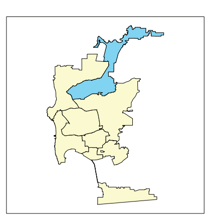
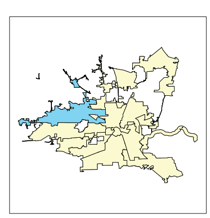
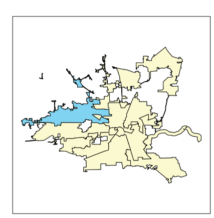
Since the publication of our 2006 white paper, redistricting at the local level has been in the news (and the courts) in several parts of the country. In 2009, local officials filed a lawsuit against the City of Houston, arguing that city council was in violation of its own charter by refusing to add two districts after the population passed the 2.1 million mark in late 2006. The case was rejected in Federal district court, allowing Houston to hold off on redistricting efforts until after population figures from the 2010 census are released. In Cleveland, city council members approved a redistricting plan in March 2009 that reduced the number of wards from 21 to 19 for the November 2009 municipal elections. The population of this rust-belt city has been steadily declining over the past 50 years, and a city charter amendment, passed in November 2008, called for a redrawing of the ward maps to reflect the reduced population. An outside consultant planned the new boundaries, and the process was contentious within city council ranks. Council leaders provided the narrowest of windows for citizen review of the new plan, releasing it at a public hearing on a Friday evening and voting to approve it the following Monday night. Like most cities throughout the United States, Cleveland will redistrict again after the 2010 census.

Many of the local districts and wards that topped our list of least compact districts in 2006—including Houston—also landed on the lists we generated for this study, with several key differences. Why? First, our methodology has changed. Previously, we used just one measure, Polsby-Popper, to calculate district compactness. In this analysis, we use four measures that capture compactness in different ways. We also tried to account for the shapes of legislative districts in coastal areas by running calculations on distinct geographical components of a district (islands, for example) and then summing the results of the calculations. (See a full discussion of methodology above.)

Compactness scores

We began our study by using the four measures—Reock, Convex Hull, Polsby-Popper, and Schwartzberg—to generate four different compactness scores for each local legislative district. We performed these calculations on the shapefiles of the 50 largest cities[6] in the country. Some cities, like Seattle, Portland, Detroit, Austin, and Columbus do not have geographic districting, instead allowing all residents to vote for all local offices (also known as "at large" councils), and were thus excluded from our analysis. In total, we calculated compactness scores for political districts in 42 of the top 50 largest cities in the country. We multiplied the compactness score by 100, giving a range of 0 to 100, with 0 being the least compact. **Table 4** displays the Top Five least compact local legislative districts by measure of compactness.

Table 4: Top Five least compact local districts by compactness score

Reock	Convex Hull	Polsby-Popper	Schwartzberg
1. Miami, FL–District 2 Compactness score: 2.51 	**1. Houston, TX–District E** Compactness score: 25.80 	**1. Houston, TX–District B** Compactness score: 15.84 	**1. Houston, TX–District 2** Compactness score: 9.6 
2. Houston, TX–District E Compactness score: 10.78 	**2. Houston, TX–District A** Compactness score: 33.38 	**2. Miami, FL–District 2** Compactness score: 2.52 	**2. Miami, FL–District 2** Compactness score: 15.87 
3. New York, NY–District 4 Compactness score: 11.44 	**3. Phoenix, AZ–District 6** Compactness score: 35.86 	**3. Houston, TX–District E** Compactness score: 3.10 	**3. Houston, TX–District E** Compactness score: 17.61 
4. Los Angeles, CA–District 15 Compactness score: 11.99 	**4. Chicago, IL–Ward 30** Compactness score: 35.93 	**4. Ft Worth, TX–District 7** Compactness score: 3.16 	**4. Ft Worth, TX–District 7** Compactness score: 17.78 
5. San Bernardino, CA–District 6 Compactness Score: 12.92 	**5. San Diego, CA–District 5** Compactness score: 37.34 	**5. Houston, TX–District A** Compactness score: 3.19 	**5. Houston, TX–District A** Compactness score: 17.85 

A look at the maps of these areas quickly reveals both the strengths and weaknesses of using compactness alone as a proxy for gerrymandering. The compactness of a district can be greatly impacted by both physical features and political boundaries, and low compactness due to one of these factors would not necessarily be indicative of gerrymandering. The role of physical features can be seen quite clearly in the case of Miami–2, a district that appears on the Reock, Polsby-Popper, and Schwartzberg lists. The impact of physical geography is most obvious in coastal regions, where islands, capes and inlets add to the perimeter without corresponding increases in area, thus lowering compactness. Interestingly, this is one area where the more detailed the data (in this case, the shapefile), the more skewed the results will be. Highly generalized data, with rough estimates of coastlines, will yield much higher compactness scores than more detailed data following each twist and turn.

Houston and Fort Worth boast several districts in the Top Five for all four measures (and two additional Fort Worth districts in the Top Ten for the Polsby-Popper and Schwartzberg measures). The city council districts in these cities do have convoluted shapes, with all of the odd twists and protrusions characteristic of gerrymandering. A close examination, however, reveals that these districts do follow boundaries of each city, deriving their bizarre shapes from a history of growth by annexation, rather than by specific manipulation of internal district boundaries. These are likely cases of "tax-base gerrymandering"—when a municipal government extends its boundary along a highway or river in order to capture the higher tax base of an outlying suburb—rather than gerrymandering in the traditional sense.

An index

So, having now declared that several of our top local districts (based on compactness scores) are probably *not* gerrymandered, what other approaches can we take to identify gerrymandered districts? Is there some way to account for the effect of municipal boundaries on the compactness of a district? To address this concern, we calculated the compactness values of the city as a whole and divided the district compactness score by the city compactness score. The result is an index, a normalization of a district's compactness by the compactness of its parent city. An index value less than 1 represents a district that is less compact than the city in which it is located, while a value greater than 1 represents a district that is more compact than its city. Using this method puts us at risk of ranking moderately compact districts in highly compact cities above districts of very low compactness that are in low or moderately compact cities. To address this concern, we used the individual district compactness to identify potentially gerrymandered areas and performed the additional analysis only on those districts. Districts were identified as being potentially gerrymandered if their individual compactness scores were more than one standard deviation below the mean compactness score for all districts (**see Table 5**).

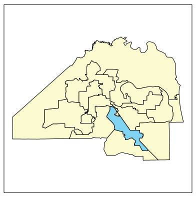
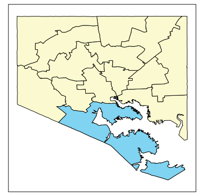
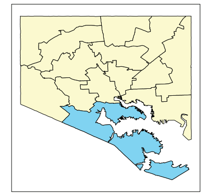
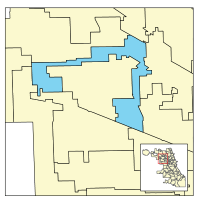
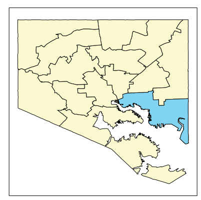
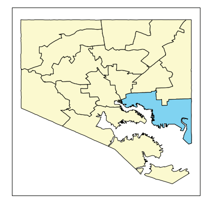
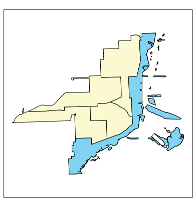
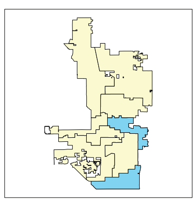
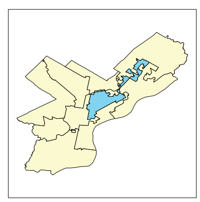
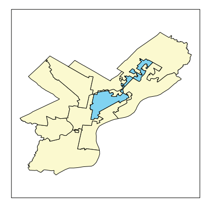
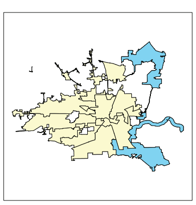
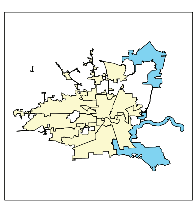
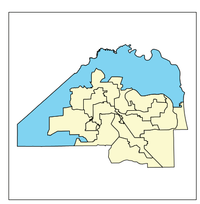
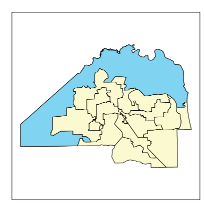
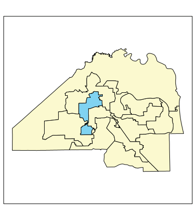
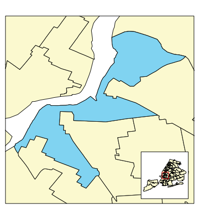
We should note here that scores are not comparable across measures. A district receiving a compactness score of 35 using the Reock measure cannot be directly compared to a district receiving a compactness score of 35 using the Polsby-Popper measure. Each measure captures a different characteristic of compactness. (Although some districts—San Francisco's District 4, for example—have features that place them on the most compact or least compact lists for several measures.) Likewise, the values for the compactness indices for each district are not comparable across measures. **Table 6** displays the Top Five least compact local legislative districts by compactness index.

Table 5: Summary statistics for local district compactness scores

	Reock	Convex Hull	Polsby-Popper	Schwartzberg
Mean	36.74	70.17	28.30	51.24
Standard Deviation	11.53	12.39	14.76	14.34
Minimum	9.6 (Miami–2)	25.80 (Houston–E)	2.51 (Houston–B)	15.85 (Houston–B)
Maximum	71.70 (Philadelphia–3)	98.43 (San Francisco–4)	76.27 (San Francisco–4)	87.34 (San Francisco–4)

n = 528 local legislative districts (42 cities) included in this analysis

Table 6: Top Five least compact local districts by index

Reock Index	Convex Hull Index	Polsby-Popper Index	Schwartzberg Index
1. Jacksonville, FL–District 5 Index: 0.29 (Compactness: 16.82) 	**1. New York, NY–District 4** Index: 0.52 (Compactness: 40.69) 	**1. Baltimore, MD–District 10** Index: 0.06 (Compactness: 4.97) 	**1. Baltimore, MD–District 10** Index: 0.26 (Compactness: 22.30) 
2. New York, NY–District 4 Index: 0.30 (Compactness: 11.44) 	**2. Chicago, IL–Ward 30** Index: 0.5452 (Compactness: 35.92) 	**2. Baltimore, MD–District 1** Index: 0.15 (Compactness: 10.75) 	**2. Baltimore, MD–District 1** Index: 0.38 (Compactness: 32.78) 
3. Miami, FL–District 2 Index: 0.32 (Compactness: 9.66) 	**3. Phoenix, AZ–District 6** Index: 0.5453 (Compactness: 35.86) 	**3. Philadelphia, PA–District 7** Index: 0.24 (Compactness: 7.64) 	**3. Philadelphia, PA–District 7** Index: 0.48 (Compactness: 27.65) 
4. Houston, TX–District E Index: 0.33 (Compactness: 10.78) 	**4. Houston, TX District E** Index: 0.56 (Compactness: 25.80) 	**4. Jacksonville, FL–District 11** Index: 0.27 (Compactness: 12.70) 	**4. Jacksonville, FL–District 11** Index: 0.52 (Compactness: 35.65) 
5. Jacksonville, FL–District 10 Index: 0.376 (Compactness: 21.79) 	**5. New York, NY–District 33** Index: 0.586 (Compactness: 45.91) 	**5. Nashville, TN–District 13** Index: 0.32 (Compactness: 12.16) 	**5. Nashville, TN–District 13** Index: 0.56 (Compactness: 34.87) 

Discussion

Philadelphia–7, New York–4, and Chicago–30—districts in cities with long histories of gerrymandering—rose to the top of the index lists presented in Table 6. Two additional districts from New York and one additional district from Philadelphia landed in the Top Ten, and several more districts from New York, Philadelphia, and Chicago landed in the Top 20. The use of an index eliminates many of the districts in Houston and Fort Worth that rose to the top of the compactness score lists displayed in **Table 4**. However, Houston's District E—on the periphery of the city and stretching along highways to include the far flung areas of Kingwood, the Houston Ship Channel, and Ellington Field Airport—still turns up on the list of worst offenders using the Reock and Convex Hull measures.

Miami's 2nd District, which captures the city's entire coastal boundary, is the only district that appears on the Top Ten index list for all four measures (only the Top Five are displayed here). Its distinct characteristics—long, thin, and boomerang-shaped, with a detailed coastline and many islands—generate low scores for both dispersion and indentation measures. The district is also an area of low compactness in an otherwise compact city. Two additional coastal districts emerge on the Polsby-Popper and Schwartzberg index lists—Baltimore 10 and Baltimore 1. Both of these districts are heavily influenced by their border with the Chesapeake Bay. Although non-contiguity is often a sign of gerrymandering, in this case it is a result of natural boundaries. Additionally, it is likely that highly detailed data on the Chesapeake is disproportionately increasing the perimeter of the surrounding districts. These districts also emerge on the index lists because they are areas of low compactness (many indentations) in an otherwise compact city with smooth boundaries.

While Jacksonville, Florida is well-known for its gerrymandered districts—several were designed to capture the votes of minority communities—the shape of District 11 appears to be influenced by the path of the Nassau River on the northern border of the city and several other river insets and bays that feed into the Atlantic Ocean.

Nashville's Districts 13 and 33 appear on the Polsby-Popper and Schwartzberg lists because the presence of a large reservoir between the two districts creates convoluted district boundaries. The reservoir—and several islands in the middle of the reservoir—is actually included in the boundaries of District 13. Nashville 33 includes large swaths of land on both sides of the reservoir, connected by a highway.

No mathematical formula is likely to adequately correct for all of this variability. As with any indicator, we suggest that our index be used to identify areas of *potential* gerrymandering, but that the particulars of each case should also be used as a guide.

Top 10 States

In addition to assessing the compactness of individial districts, we used the four compactness measures to evaluate districting at the state level by averaging the compactness of all districts in the state, for each legislative level. The Top Ten lists were compiled and sorted by converting each compactness measure into a z-score and determining the average of the state's z-scores across the four measures. As with the individual district scores, these Top Ten lists differ from those in our 2006 white paper because of changes to our methodology and data set. Perhaps most notably, the formerly top-ranked Georgia has disappeared from the list entirely as a result of considerably more compact Congressional legislative district boundaries that went into effect beginning in November 2006.

At the congressional level, four states are notable for their appearance in the list of Top Ten least compact states for all of the measures: Maryland (ranking 1 or 2 by all measures), West Virgina, Florida and Massachusetts (**Table 7**).

At the state senate (upper house) level, four states again share the distinction of appearing in the list of Top Ten least compact states for all of the measures: Florida (which was ranked 1 or 2 by all measures), California, Massachusetts and Pennsylvania (**Table 8**).

At the state assembly (lower house) level, four states are notable for their appearance in the list of top ten least compact states for all of the measures: Mississippi (which was ranked 1 or 2 by all measures), Tennessee, Florida and Louisiana (**Table 9**).

Table 7: Top Ten states whose U.S. House districts have the lowest average compactness

	Convex Hull	Reock	Polsby-Popper	Schwartzberg
MD	2	2	1	1
WV	1	6	3	3
FL	3	3	10	7
MA	5	4	7	10
NJ	4	14	5	5
NH	15	1	14	15
CA	8	5	11	9
NC	9	22	2	2
TN	12	8	8	8
PA	10	15	4	4

Table 8: Top Ten states whose state upper house districts have the lowest average compactness

	Convex Hull	Reock	Polsby-Popper	Schwartzberg
FL	1	1	2	2
CA	4	2	1	1
MA	2	7	3	3
PA	3	6	7	6
NY	5	3	16	13
SC	7	19	4	5
TN	9	15	5	7
WV	13	10	9	9
MD	18	12	6	4
VA	10	9	10	12

Table 9: Top Ten states whose state lower house districts have the lowest average compactness

	Convex Hull	Reock	Polsby-Popper	Schwartzberg
MS	1	2	1	1
TN	2	6	2	2
FL	4	4	6	6
NV	3	1	12	13
CA	12	12	3	5
NJ	5	3	13	14
KY	11	18	4	4
NY	7	7	11	11
LA	8	9	7	8
MD	16	16	5	3

Discussion

While each method has its strengths and weaknesses in terms of the particular aspects of compactness it captures, it is crucial to understand some of the practical implications of these measures. First, we must bear in mind that compactness is a mathematical proxy for gerrymandering, not an absolute assessment of the phenomenon. No mathematical formula is likely to adequately correct for all of the geographical and social variability that can result in irregular district shapes.[7]

District boundaries may deviate from an ideal shape because they are following a natural boundary like a shoreline or a mountain ridgeline. In urban areas, high population densities mean that districts are often formed by aggregating very small geographical areas, such as census block groups, which typically leads to far more contorted boundaries than the aggregation of large areas, like counties, in more rural areas. The Polsby-Popper and Schwartzberg measures are particularly sensitive to such changes in district boundaries, but all of the compactness measures we examined exhibited something of a bias against urban areas in this regard. Districts may also be drawn to conform with outcome-based criteria, like the promotion of competitiveness or adherence to the requirements of the Voting Rights Act.

It is also important to account for the appearance of second-order bias. While geometric compactness measures may appear to be neutral, combined with geography and real-life patterns of population distribution they may produce reliable political outcomes. One study concluded that a compactness requirement reduces the representation of racial minorities.[8] Other scholarly work identifies a variety of biases inherent in automated redistricting and compactness standards, including favoring the majority political party.[9] Clearly, other important components of the redistricting process, such as aggregation of "communities of interest" are not necessarily well served by examining only compactness.

A number of scholars have suggested that compactness measures are best used not as absolute standards against which a single district's shape is judged, but rather as a way to assess the relative merits of various proposed plans. Above all, compactness is most meaningful within the framework of an institutional redistricting process.

Redistricting Practices

Technology & Process

While there has been a fair amount of speculation about the role of geographic information systems (GIS) technologies in facilitating gerrymanders—including in the first edition of this white paper—little scholarship has documented a direct link. Indeed, what research has been done seems to suggest the opposite effect, that the widespread availability of computers has been beneficial to redistricting.[10]

What has changed since the last Census in 2000 is the cost and availability of computing power. In the past 10 years computer processing power has steadily increased and hardware costs have decreased to the point that technologies that were once affordable only by government institutions or powerful political parties are now accessible by advocacy organizations and the general public. Similarly, the growing Internet infrastructure means that many of the spatial analysis techniques that have long been restricted to expensive and specialized desktop software packages can now be delivered over the web.

What are the implications of this for the redistricting process? Gerrymandering has long thrived on secrecy and back-room dealing that is facilitated by the fact that most redistricting processes are entrusted to the very legislators who will run in the newly-drawn districts.

States have experimented with ways of making the redistricting process more transparent. In 2001 many states and localities set up websites where they made redistricting information available to the public. A few cities distributed data and software to the citizens to encourage their active participation in the redistricting process. That same year, Idaho set up computer stations in a handful of libraries around the state to enable the public to create and submit redistricting plans. More recently, Ohio conducted a redistricting competition in which entrants could download data and software over the web, and would electronically submit their plans to the Secretary of State for judging.

Advances in technology since the last major round of redistricting almost 10 years ago offer the opportunity to make the process more transparent than ever. We believe that a confluence of the Internet, geographic data, and tools for online collaboration have the potential to transform the redistricting process by enabling citizens to participate directly in these efforts. The University of Southern California's Annenberg Center for

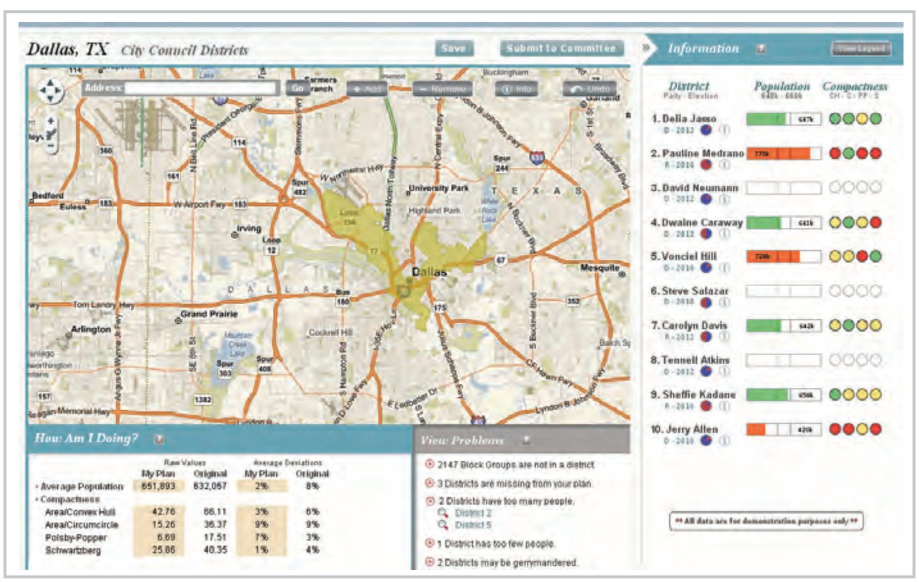


Figure 9: Sample interface for a web-based redistricting application

Communications took a step in the right direction with its launch of The Redistricting Game as a tool for public engagement, and at least one individual has developed an online tool for creating Congressional districts based on Census data.

A Web 2.0 approach to redistricting would enable citizens to work with real data in a user-friendly, game-like interface (**Figure 9**). Web-based tools could make it possible for citizens and community groups to create their own redistricting plans, share those plans with others, assess the fairness of plans, vote on their favorite plans, and submit the best plans to their local and state redistricting authorities or legislatures. Above all, however, web-based redistricting can make the process engaging and interactive, involving citizens in what should be a key democratic process.

Conclusion

Although district compactness is frequently cited as a traditional districting principle, due to the variety of factors that come into play in determining legislative boundaries, gerrymandering is rarely simple to identify. Truly bizarre and convoluted shapes can result from processes unrelated to partisan redistricting schemes. Physical landscape features from coastlines to mountain ranges impact decisions on where to draw district boundaries and unusual growth patterns create convoluted cities, rendering compact district design all but impossible. Because of the combined impacts of political boundaries and physical geography, other factors may be taken into consideration when looking at a particular district, such as shape, contiguity and respect for political subdivisions. Moreover, many goals of gerrymandering are possible to achieve without resorting to strange district shapes.

The compactness measures discussed in this white paper attempt to quantify the extent to which a local, state or federal district may be gerrymandered. While the peculiarities and limitations of the various measures are apparent from our research, a low compactness score nonetheless serves as an indicator that gerrymandering is likely and points the way to districts worthy of higher scrutiny. Many of the districts that appear in our Top Ten lists of least compact districts (see Appendix) will come as no surprise to political observers, particularly at the Congressional level. A number of them have been the subject of contention and even litigation. What likely is surprising to those unfamiliar with the redistricting process is that the Supreme Court has ruled in several cases that gerrymandering—including partisan gerrymandering—can be perfectly legal.

Several states in the United States have addressed gerrymandering problems by the establishment of independent redistricting commissions, usually composed of retired judges. While this is a positive step forward, independent redistricting commissions are rarely sufficient to guarantee both competitiveness and fair representation. Reform organizations such as FairVote have also called for the establishment of multi-seat 'Superdistricts' with selection occurring through proportional representation in order to improve both partisan balance, competitiveness, voter turnout and representation of racial minorities.

Either of these systems would represent an improvement over the partisan manipulation or bipartisan collusion that characterize many current redistricting processes, but they don't necessarily achieve the truly democratic goal of engaging the citizenry. Although GIS technologies have enabled gerrymandering in the past, changes in their cost and availability mean that they are now poised to offer a solution. A web-based redistricting application has the potential to reduce gerrymandering through a transparent and open process that engages the public. Drawing geographically meaningful boundaries means that citizens will finally have the opportunity to elect the representatives that they want rather than allowing politicians to select them.

Endnotes

1 In the 2006 version of this white paper the prior boundaries were still in effect and three Georgia districts appeared in our list of the Top Ten most gerrymandered federal districts. The new, more compact boundaries went into effect with the election of the 110th Congress in November 2006 are used in this analysis, which is one of the reasons why GA-13, GA-11 and GA-08 no longer appear.

2 Polsby and Popper, "The Third Criterion: Compactness as a Procedural Safeguard Against Partisan Gerrymandering," Yale Law & Policy Review 9, 1991, pp. 301-353.

3 Altman, Chapter 2, "The Consistency and Effectiveness of Mandatory District Compactness Rules" in "Districting Principles and Democratic Representation." Diss. California Institute of Technology, 1998.

4 Reock, "A Note: Measuring Compactness as a Matter of Legislative Apportionment," Midwest Journal of Political Science, 5(1), 1961 pp. 70-74.

5 Niemi et al., "Measuring Compactness and the Role of a Compactness Standard in a Test for Partisan and Racial Gerrymandering," Journal of Politics, 52 (4), 1990, pp. 1155-1179.

6 The Cicero database does not include spatial data for Louisville, KY, Indianapolis, IN, or Memphis, TN.

7 For a discussion of the biases of various compactness measures, see H.P. Young, "Measuring the Compactness of Legislative Districts," Legislative Studies Quarterly, 13 (1), 1988, pp. 105-115.

8 Barabas & Jerit, "Redistricting Principles and Racial Representation," State and Politics Quarterly¸4 (4), 2004, pp. 415-435.

9 Altman, "Is Automation the Answer? - The Computational Complexity of Automated Redistricting," Rutgers Computer and Technology Law Journal 23 (1), pp. 81-142, 1997.

10 Altman et al., "Pushbutton Gerrymanders? How Computing Has Changed Redistricting" in Party Lines: Competition, Partisanship, and Congressional Redistricting, Mann and Cain, eds., New York: Brookings Institution Press, 2005.

Additional Resources

American Civil Liberties Union
Everything You Always Wanted to Know About Redistricting But Were Afraid to Ask
http://www.aclu.org/FilesPDFs/redistricting_manual.pdf

Americans for Redistricting Reform
http://www.americansforredistrictingreform.org/

Brennan Center for Justice, New York University School of Law
A Citizen's Guide to Redistricting
http://www.brennancenter.org/content/section/category/redistricting/

Brookings Institution
Congressional Redistricting
http://www.brookings.edu/topics/congressional-redistricting.aspx

Center for Governmental Studies
Drawing Lines: A Public Interest Guide to Real Redistricting Reform
http://www.cgs.org/index.php?view=article&id=120%3APUBLICATIONS&option=com_content&Itemid=72

FairVote: Voting and Democracy Research Center
State-by-state redistricting reform information
http://www.fairvote.org/index.php?page=1389

Gerrymandering: a new documentary film
http://www.gerrymanderingmovie.com/

The Redistricting Game
http://www.redistrictinggame.org/

Wolfram Demonstrations Project
Mathematical demonstration of compactness measures
http://demonstrations.wolfram.com/AMinimalCircumcircleMeasureOfDistrictCompactness/

United States Elections Project, George Mason University
http://elections.gmu.edu/Redistricting.html

University of California San Diego, Social Sciences and Humanities Library
Baffling Boundaries: the Politics of Gerrymandering
http://sshl.ucsd.edu/gerrymander/

United States Census Bureau
Redistricting Data Office
http://www.census.gov/rdo/

Minnesota State Legislature
Redistricting 2010 resources
http://www.commissions.leg.state.mn.us/gis/html/redistricting.html

National Conference of State Legislatures
Redistricting resources
http://www.ncsl.org/Default.aspx?TabID=746&tabs=1116,115,786#1116

League of Women Voters of Pennsylvania
Redistricting resources
http://palwv.org/issues/2008Redistricting.html

APPENDIX

Top Ten Congressional Districts by Compactness Score

Reock

District	Compactness Score
CA–23	4.65
FL–22	8.30
NY–8	9.24
FL–18	10.07
NY–28	11.28
NJ–13	11.39
NC–12	11.53
FL–3	12.59
MD–6	13.50
MA–3	13.62

Convex Hull

District	Compactness Score
CA–23	22.58
NY–28	27.38
IL–4	32.77
FL–22	33.55
NC–12	34.79
MA–10	35.48
NJ–6	35.55
IL–17	40.41
MD–2	41.79
NY–8	41.97

Polsby-Popper

District	Compactness Score
MD–2	2.04
MD–1	2.09
FL–22	2.66
MD–5	2.76
NC–12	3.49
IL–4	3.77
CA–23	4.02
PA–12	4.98
MD–3	4.98
NJ–6	5.41

Schwartzberg

District	Compactness Score
FL–22	16.32
MD–5	17.12
NC–12	18.67
MD–2	18.82
IL–4	19.41
MD–1	21.11
PA–12	22.31
NJ–6	23.25
MD–3	23.42
PA–18	24.14

Top Ten State Upper Districts by Compactness Score

Reock

District	Compactness Score
FL–29	4.15
IL–13	9.70
NY–31	9.92
RI–36	10.68
FL–8	11.16
FL–1	12.08
NY–28	12.67
MN–7	13.17
FL–4	13.24
GA–39	13.54

Convex Hull

District	Compactness Score
FL–29	23.52
NM–31	29.05
MS–47	32.30
PA–3	34.02
MN–7	37.54
MA–Cape & Island	40.74
NY–51	40.94
FL–27	41.10
MD–47	42.08
TX–17	42.15

Polsby-Popper

District	Compactness Score
MD–37	2.20
MA–Cape & Island	3.41
MD–36	3.89
FL–29	3.89
MS–47	4.08
ME–20	4.20
MD–6	5.00
ME–10	5.13
FL–18	5.16
MD–29	5.19

Schwartzberg

District	Compactness Score
MD–37	17.84
FL–29	19.72
MS–47	20.21
MD–6	22.37
FL–18	22.72
MD–36	22.73
MD–31	24.33
MD–29	24.75
NY–34	24.88
TX–6	26.29

Top Ten State Lower Districts by Compactness Score

Reock

District	Compactness Score
IL–5	7.86
MT–31	7.97
IL–26	8.89
AK–5	10.82
MS–97	11.06
IN–1	11.51
LA–21	11.65
AL–46	12.01
MA–4th Barnstable	12.11
TN–87	12.25

Convex Hull

District	Compactness Score
MS–95	32.36
MS–97	32.38
AK–5	35.95
MS–37	36.66
MA–4th Barnstable	36.66
TN–90	36.73
PA–170	37.70
PA–202	37.91
NY–23	38.24
MS–25	38.90

Polsby-Popper

District	Compactness Score
MD–37B	1.51
MA–4th Barnstable	3.02
MD–36	3.89
ME–64	4.04
TN–80	4.19
WI–64	4.26
MS–97	4.30
MS–25	4.64
MS–37	4.66
MS–34	4.72

Schwartzberg

District	Compactness Score
MD–37B	15.17
TN–80	20.46
MS–97	20.73
WI–64	21.02
MS–25	21.54
MS–37	21.59
MS–34	21.73
MD–6	22.37
MD–36	22.73
MA–4th Barnstable	23.53