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Geographic Information System and Gerrymandering

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Abstract

Gerrymandering is the practice of manipulating voting district boundaries to gain political advantage in democratic voting. The geographic information system (GIS) becomes a versatile tool for that. This paper describes how to use the GIS for gerrymandering, in the practice of both cracking - diluting the opponents voting into many districts, and packing - concentrating the opponent's voters into fewer districts. The use of GIS makes extreme gerrymandering relatively easy to do. Even when we understand it to be bad for democracy since it facilitates for the politician to choose his/her voters, gerrymandering is generally allowed by law. Restricting the practice of gerrymandering turns out to be a legally challenging proposition. We discuss some approaches to legislation against gerrymandering. Believing that the GIS can be part of the solution, we call for GIS researchers to work with legal professionals to formulate regulations to contest and disallow gerrymandering.

Keywords: Gerrymandering, GIS, Geographic Information System.

1. INTRODUCTION

Gerrymandering is the practice of manipulating voting district boundaries to gain political advantage in democratic voting (Griffith 1907). Re-districting is necessary for demographic changes such as birth, death, population migration as well as immigration. By law, a census is done every ten years, and the government has the duty and the right to re-districting. The state law in some states may have the stipulation that the adjustment of voting district boundaries is to preserve the democratic election of government by voting. Nevertheless, it is legal for the political party in power to gain political advantage by gerrymandering, since the law was never written specifically to identify it and disallow it.

Partisan gerrymandering was not a serious problem until the past decade. Generally, it was not an easy task to do. However, the use of geographic information system (GIS) along with the availability of data has made it quite practicable (Reitsma 2013). Some attempted to automate the process (Li, Wang & Wang 2007; Yamada 2009; Siegel-Hawley 2013). Quite a few

visionary researchers sought to identify it and disallow it (Niemi, Grofman, Carlucci & Hofeller 1990; Flint 2003; Chou & Li 2006; Ricca, Scozzari & Simeone 2008). If partisan gerrymandering is identified, it may be contested in court and legally disallowed. Many are then calling for research in this area (Forest 2018; Crane & Grove 2018; Grofman & Cervas 2018). Following the past effort, this paper describes how the GIS has become the tool for gerrymandering, and suggest that it may become part of the solution with further research.

Section 2 will present a brief history of the term gerrymandering. It was widely perceived as bad for democracy but it has always been legal. Section 3 will summarily explain the two fundamental strategies of gerrymandering: how to do re-districting to gain political advantage. A few simple figures help to explain that. While there is no existing algorithm to automate gerrymandering, the GIS becomes a viable tool to make it easy. Section 4 goes on to describe how to leverage the GIS interactive functionalities, visualization on the map and spatial data analysis to do gerrymandering. Section 5 begins the discussion of how we may prevent the practice of gerrymandering, suggesting various approaches. Some of these are primarily socio-political, but some inevitably involves geographical and social data analysis. Section 6 presents the summary and a statement of conclusion.

2. BRIEF HISTORY

Elbridge Gerry (1744-1814) was a politician among the founding fathers of the United States of America; a portrait of him is below in Figure 1.

Fig.1 Elbridge Gerry

In 1812, the Massachusetts state governor Elbridge Gerry (1744-1814) signed a bill that created a voting district in the shape of a salamander, intended to gain political advantage. The map of the proposed voting district is illustrated in Figure 2. Approved by the state legislature, the bill then also coined the term "gerrymandering" to refer to the practice of manipulating voting district boundaries to gain political advantage (Griffith 1907).

Periodic re-districting is necessary to allow effective administration of voting by drawing the voting districts according to population distribution. By the U.S. constitution, the federal government cannot dictate how the states may define the voting districts. Every state government sets up its own policy. The political party holding majority in the state government therefore has the privilege to re-draw the voting districts, possibly manipulating that for political gain. Including the US census every 10 years, there is always updated demographic information about the population to justify re-drawing the voting districts. The intention for doing so is difficult to contest.

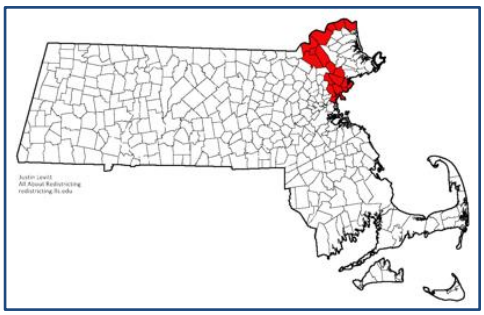

Fig.2 Voting District by Governor Gerry 1812.

Gerrymandering is practically legal. However, it has not been a major issue until more recently, in the past decade. Voting districts drawn for political advantage now begin to show up in evidently very strange shapes and much more often. We believe the common use of GIS today together with the ease of access to data has made it simple to achieve. In the next section, we will discuss the strategies of gerrymandering, and how the GIS makes it much easier.

3. GERRYMANDERING IN PRACTICE

How does the GIS make gerrymandering easy? Let us first examine how to do gerrymandering. Fundamentally, there are two basic strategies: cracking and packing. The choice depends on whether or not the political party has the majority of the votes. Simple illustrations in figures 3, 4 and 5 will explain the ideas quite well.

Suppose the two political parties are A and B. Party A has the majority, 55% of the votes, while Party B has 45%, being the minority. Figure 3 illustrates the hypothetical distribution of the population in a square sample piece of land, and it depicts a simplistic way to form 5 voting districts in five vertical strips. Party A

wins 3 districts two of which having 100% of the votes and one district by 75% of the votes. Party B wins 2 districts by 100% of the votes and loses 1 district with only 25% of the votes in one district. Party A has the majority while Party B still has a substantial minority.

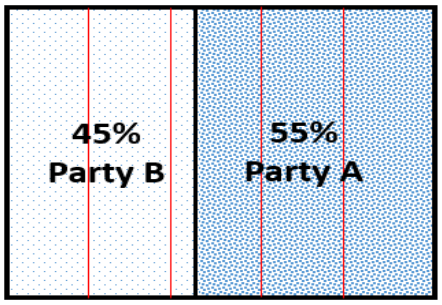

Fig.3 Majority wins 3; Minority 2.

Cracking

Cracking is the approach to dilute the votes of the opposing party to suppress them from winning in any voting district. Suppose Party A is in power, and re-draws the voting districts into 5 horizontal strips, as illustrated in Figure 4. In each of the 5 districts, Party A has the 55% majority and Party B has the 45% minority. Hence Party A wins all 5 districts and Party B loses in all 5 and does not even have a minority say now. The re-districting strategy has distributed the voting power of Party B and suppressed them from winning any district. Cracking is the approach when the party has the majority.

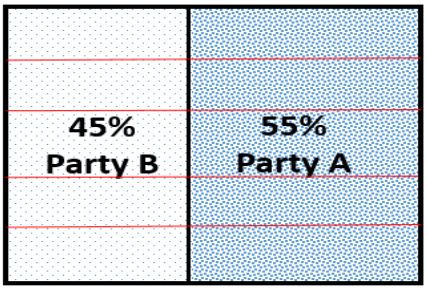

Fig.4 Cracking to Eliminate the Minority.

Packing

Packing is the approach to concentrate the votes of the opposing party in one or few districts to reduce their votes in other districts. Suppose Party B is in power but realizes that they have overall only 45% of the popular votes. In order to gain political advantage, the voting districts are re-drawn, illustrated in Figure 5. One voting district is a vertical strip to the right, with 100% of the votes for Party A. Party A wins the district. But the rest of the area is divided into 4 horizontal strips for the 4 districts. Now in each of these 4 districts, Party B wins by the ratio of 45-to-35, winning in all 4 districts. The result of gerrymandering is that the minority Party B wins 4 districts and the majority Party A wins only one. Packing is the approach when the party has the minority, packing the majority party in one or few districts, reducing their voting power in the rest.

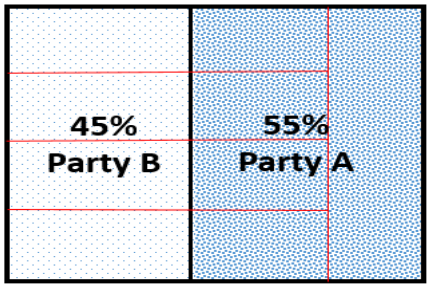

Fig.5 Packing to Limit the Majority.

4. GIS FOR GERRYMANDERING

The simplistic population distribution assumed in our hypothetical map makes it easy for us to explain and illustrate the two fundamental strategies of gerrymandering. In a real situation, it may not be so easy to form the voting districts to achieve cracking or packing. Theoretically, no algorithm exists to exhaustively search for all feasible solutions in gerrymandering.

A better approach is to use the GIS for interactive decision support. We need to first gather the data about where the voters are and which side they are likely to vote for. Such a map presented by the GIS will serve as a visual guide to see where the voters are located. The process is known in the GIS functionality as geocoding (Wu & Rathswohl 2010).

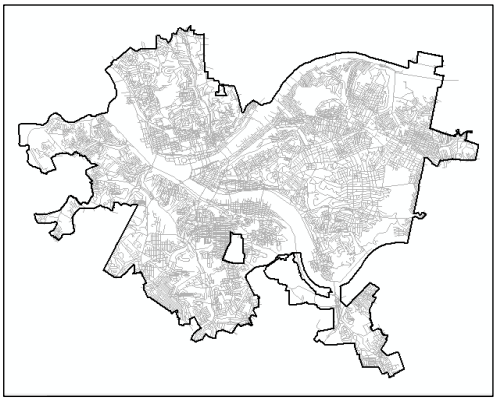

Fig.6 A City Street Map

To illustrate that in a simple way, suppose we have done the foot work of collecting the resident addresses of our political supporters who are to vote for us in a certain city. Figure 6 below shows a street map of the city.

Depending on the level of granularity desired for our map, it may be polygon geocoding just to identify the number of voters on each side within each area unit, or we may apply linear geocoding if we want to identify the point location of each voter (Goldberg 2016). For our illustration, we applied linear geocoding: from the collected addresses, the GIS produces a point map showing where each voter is located by the address. Figure 7 below shows the point map produced by geocoding superimposed on the street map.

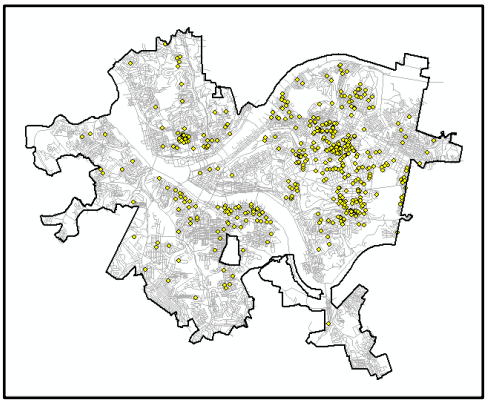

Fig.7 Geocoded Address Locations

Once we have the map to visualize where the voters are, we can use that as our guide to draw the desirable voting district boundaries. Suppose we want to make sure that one substantial group of our supporters in the north east will win in one district. We then draw on the map our desired district, as shown in Figure 8 below.

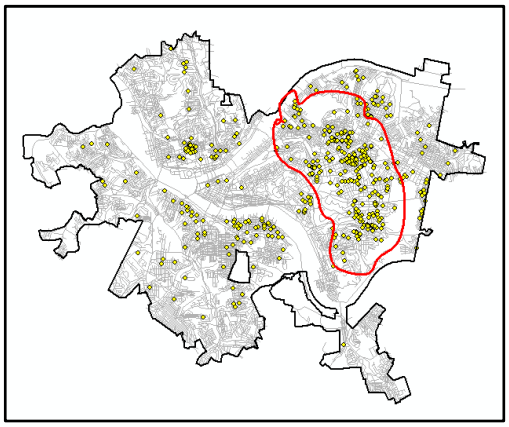

Fig.8 Drawing a voting district

For every district drawn, the functionality known as spatial join of the GIS allows us to immediately calculate the number of our supporters included there, and we can therefore project how likely we may win the voting district.

Suppose we recognize that our supporters do not constitute the majority and therefore need to at least win 3 districts. We can try drawing districts in various shapes, evaluating in each case, until we find the ones we desire. This trial and test approach guided by the visualized map becomes a very practicable way to obtain a robust solution for gerrymandering. Figure 9 shows our desired result of three districts, practicing extreme gerrymandering.

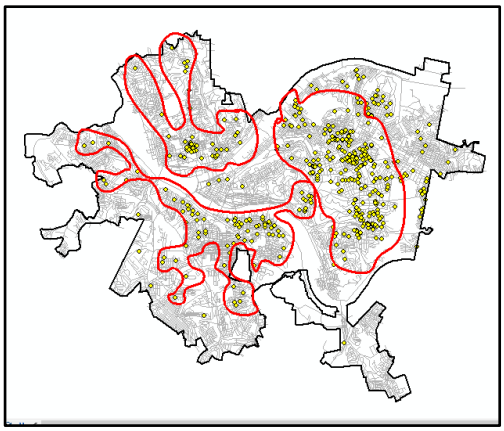

Fig.9 Gerrymandering result in 3 districts

Past attempts to fully automate the process using GIS were not successful (Li, Wang & Wang 2007; Yamada 2009; Siegel-Hawley 2013). There is significant difficulty in traversing or iterating the varieties of options in forming geometric shapes. Whereas using the GIS as an interactive tool for gerrymandering in the computer aided process has been much more promising. In the past decade, we have seen a rising number of cases of extreme gerrymandering (Forest 2018; Crane & Grove 2018).

5. TO PREVENT GERRYMANDERING

Political re-districting is necessary to facilitate for democratic voting when there are changes in the demographics of the voting population. In the past decade, however, gerrymandering becomes a way for politicians in power exercising their rights to deeply entrench themselves with political advantage. It becomes a difficult legal issue how to contest a re-districting map as gerrymandering. There

appears to be no easy solution. In this section, we will discuss the issues about how to prevent partisan gerrymandering.

The Electoral College by the founding fathers was originally meant for proportional representation in government. 1824 marked the significant shift to the Winner-Take-All rule in having districts for presidential as well as local elections (Mccarthy 2012). To outline our suggested approaches, this section will discuss the politics of the Winner-Take-All rule and use of non-partisan commission for political re-districting first, followed by the technical issues defining gerrymandering in terms of geometry, and the possible restriction in the use of voter information in re-districting. Finally, the state laws frame the regulation about political re-districting. We think that GIS researchers should work with legal professionals about this, and hopefully, GIS may be part of the solution.

The Winner-Take-All Rule

Gerrymandering is a possible tactic because of the winner-take-all rule. The rule lets the majority winner of a voting district to claim the entire electoral count of the district. Without that rule, gerrymandering will not matter since re-districting will not affect the total count of popular votes. The rule, however, is originally designed to allow a minority population to still have a voice in a democracy when there may be at least some districts within which the minority population becomes a majority. The Voters Rights Act of 1965 requires certain states to ensure minority representation, with at least one district formed based on race (US Department of Justice 1965). Ironically, that is gerrymandering in practice. In US presidential election, some states begin to consider dropping the winner-take-all rule to count only the total popular votes. On the other hand, swing states may then lose their relevance to the candidates if the Electoral College is designated to be proportional to the popular votes. That is for each state to consider. In similar ways, local governments may consider whether or not the winner-take-all rule should be adopted in their specific situations. In either case, political districting needs to preserve a channel for the minority.

Democracy ought to be based on government by proportional representation. However, given that the Winner-Take-All Rule cannot be abolished, we may then seek to revise it for appropriate adoption. It is worthwhile to note that currently in US presidential election, Maine and Nebraska both implement a kind of hybrid combining state wide and district vote counts (Mccarthy 2012).

Non-Partisan Commission

To avoid politicians in power exploiting the opportunity of re-districting by gerrymandering, often suggested is the solution to have a non-partisan commission in charge of re-districting so that there would be no intention to gain political advantage for either side. The idea is simple but the problem is the same. The political hot potato becomes: who should be in that commission? The political problem is only re-casted in a different venue. The Non-Partisan Commission approach is practiced in Florida, but it still has to deal with the requirements of the Voters Rights Act, including the creation of districts for minority representation. The current apportionment rule requires a population of roughly 750,000 per single member district, the practice would be even more difficult when population dispersion is not so ideally congruent, but more clustered than spread out, as in the case of Pennsylvania.

It is unlikely the approach will further involve research in using and understanding GIS, we will not go on with the discussion in this paper.

Recognizing Geometry in Gerrymandering

Founded strongly in theoretical computer science, the field of computational geometry has spawned many algorithms for programming to process geometry represented in digital data (Forrest 1971; Preparata & Shamos 1988). Much of GIS functionality has been built on the results of the research work. In the introduction of this paper, we noted that earlier attempts to automate the process of gerrymandering were not successful. Realizing that extreme gerrymandering is bad for democracy, many researchers then sought to develop programming algorithms to identify partisan gerrymandering so that it might be objectively disallowed. This paper also cited as references some of the research papers. Viewers of a district map may identify weird geometric shapes as evidence of politically motivated re-districting; such evidence is hardly objective proof, much less so in the court of law. Despite many creative esoteric ideas in research, a legal definition for gerrymandering in geometric and demographic terms remains an open question. In a more recent paper, two mathematicians Alexeev and Mixon (2018) summed up in much more definitive terms about how theoretically inconclusive we can expect the approach to be. The paper was titled "An Impossibility Theorem for Gerrymandering."

Perhaps the definitive algorithmic solution is not ready. We however would note that application

of artificial intelligence with machine learning to recognize gerrymandering has not yet been much explored.

Restrict the Use of Information

Gerrymandering requires the information about location of the voters as well as their voting inclination. How the information is used in re-districting may expose the intention to gain political advantage through gerrymandering. Legislature may therefore require the appropriate justification for re-districting to indicate that it preserves or promotes democracy. The exact details of such regulation however can become very tricky to articulate, particularly when we may also note the often significant co-relation between other demographic factors such as poverty and wealth, education level, racial and ethnic origin with voting inclination. The regulations will inevitably involve the geographical and analytical issues of population data. We believe this can be a more promising approach for our research so that GIS may be part of the solution to prevent gerrymandering.

State Laws

By U.S. constitution, the federal government will not interfere with how each state may govern the districting of voting population. Two recent Supreme Court cases in June (Maryland and North Carolina) affirmed that interpretation. It is therefore up to each state government to set up the policies for political re-districting. Gerrymandering has been legal since the state laws in general were not specifically written to identify and disallow it. Some states, such as Pennsylvania, may have law stipulating that political re-districting should promote democracy. The recent case of League of Women Voters v. Commonwealth of Pennsylvania (Grofman and Cervas 2018) may shed some light on the issues.

Nevertheless, it is time for GIS researchers to work with legal professionals on the topic, for a better democracy in the future.

6. SUMMARY AND CONCLUSION

Gerrymandering is the practice to manipulating voting district boundaries to gain political advantage in democratic voting. We presented a brief history of the term, and discussed two common approaches in gerrymandering: cracking and packing. Cracking is the approach to dilute the opponent's voting power by distributing the voters into more districts so that the opponent will not win any of the districts. Packing is the approach to concentrate the opponent's voting power into fewer districts so that opponent will win only those districts. Provided with the information where the voters are, the GIS readily presents the map to visually guide our search effort in re-districting. The GIS analytic functionalities can conveniently support trial and test each potential re-districting solution for extreme gerrymandering. To preserve and promote democracy, gerrymandering should be identified and disallowed. But it is quite a challenge to legally define it. Gerrymandering is possible because of the winner-take-all rule in counting votes. The winner-take-all rule is meant to promote democracy by preserving the voice of minority groups. We will have to take that into account. To disallow gerrymandering, the state government must now heed the work of legal professionals working with GIS researchers to identify and disallow gerrymandering.

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Geographic Information System and Gerrymandering

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Partisan gerrymandering was not a serious problem until the past decade. Generally, it was not an easy task to do. However, the use of geographic information system (GIS) along with the availability of data has made it quite practicable (Reitsma 2013). Some attempted to automate the process (Li, Wang & Wang 2007; Yamada 2009; Siegel-Hawley 2013). Quite a few

visionary researchers sought to identify it and disallow it (Niemi, Grofman, Carlucci & Hofeller 1990; Flint 2003; Chou & Li 2006; Ricca, Scozzari & Simeone 2008). If partisan gerrymandering is identified, it may be contested in court and legally disallowed. Many are then calling for research in this area (Forest 2018; Crane & Grove 2018; Grofman & Cervas 2018). Following the past effort, this paper describes how the GIS has become the tool for gerrymandering, and suggest that it may become part of the solution with further research.

Section 2 will present a brief history of the term gerrymandering. It was widely perceived as bad for democracy but it has always been legal. Section 3 will summarily explain the two fundamental strategies of gerrymandering: how to do re-districting to gain political advantage. A few simple figures help to explain that. While there is no existing algorithm to automate gerrymandering, the GIS becomes a viable tool to make it easy. Section 4 goes on to describe how to leverage the GIS interactive functionalities, visualization on the map and spatial data analysis to do gerrymandering. Section 5 begins the discussion of how we may prevent the practice of gerrymandering, suggesting various approaches. Some of these are primarily socio-political, but some inevitably involves geographical and social data analysis. Section 6 presents the summary and a statement of conclusion.

2. BRIEF HISTORY

Elbridge Gerry (1744-1814) was a politician among the founding fathers of the United States of America; a portrait of him is below in Figure 1.

Fig.1 Elbridge Gerry

In 1812, the Massachusetts state governor Elbridge Gerry (1744-1814) signed a bill that created a voting district in the shape of a salamander, intended to gain political advantage. The map of the proposed voting district is illustrated in Figure 2. Approved by the state legislature, the bill then also coined the term "gerrymandering" to refer to the practice of manipulating voting district boundaries to gain political advantage (Griffith 1907).

Periodic re-districting is necessary to allow effective administration of voting by drawing the voting districts according to population distribution. By the U.S. constitution, the federal government cannot dictate how the states may define the voting districts. Every state government sets up its own policy. The political party holding majority in the state government therefore has the privilege to re-draw the voting districts, possibly manipulating that for political gain. Including the US census every 10 years, there is always updated demographic information about the population to justify re-drawing the voting districts. The intention for doing so is difficult to contest.

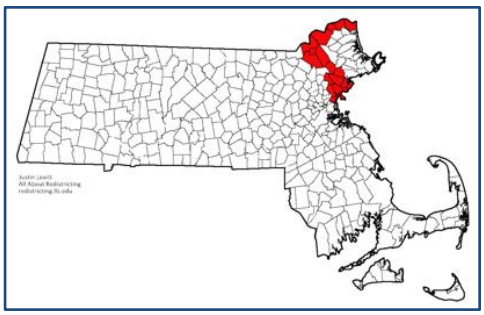

Fig.2 Voting District by Governor Gerry 1812.

Gerrymandering is practically legal. However, it has not been a major issue until more recently, in the past decade. Voting districts drawn for political advantage now begin to show up in evidently very strange shapes and much more often. We believe the common use of GIS today together with the ease of access to data has made it simple to achieve. In the next section, we will discuss the strategies of gerrymandering, and how the GIS makes it much easier.

3. GERRYMANDERING IN PRACTICE

How does the GIS make gerrymandering easy? Let us first examine how to do gerrymandering. Fundamentally, there are two basic strategies: cracking and packing. The choice depends on whether or not the political party has the majority of the votes. Simple illustrations in figures 3, 4 and 5 will explain the ideas quite well.

Suppose the two political parties are A and B. Party A has the majority, 55% of the votes, while Party B has 45%, being the minority. Figure 3 illustrates the hypothetical distribution of the population in a square sample piece of land, and it depicts a simplistic way to form 5 voting districts in five vertical strips. Party A

wins 3 districts two of which having 100% of the votes and one district by 75% of the votes. Party B wins 2 districts by 100% of the votes and loses 1 district with only 25% of the votes in one district. Party A has the majority while Party B still has a substantial minority.

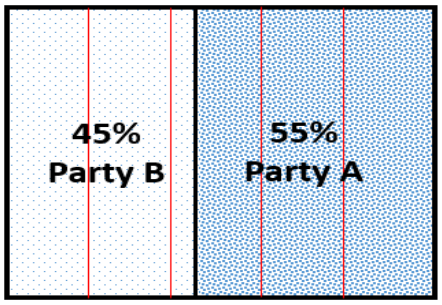

Fig.3 Majority wins 3; Minority 2.

Cracking

Cracking is the approach to dilute the votes of the opposing party to suppress them from winning in any voting district. Suppose Party A is in power, and re-draws the voting districts into 5 horizontal strips, as illustrated in Figure 4. In each of the 5 districts, Party A has the 55% majority and Party B has the 45% minority. Hence Party A wins all 5 districts and Party B loses in all 5 and does not even have a minority say now. The re-districting strategy has distributed the voting power of Party B and suppressed them from winning any district. Cracking is the approach when the party has the majority.

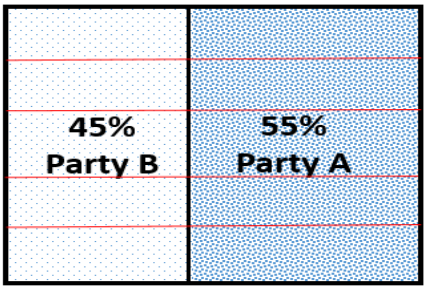

Fig.4 Cracking to Eliminate the Minority.

Packing

Packing is the approach to concentrate the votes of the opposing party in one or few districts to reduce their votes in other districts. Suppose Party B is in power but realizes that they have overall only 45% of the popular votes. In order to gain political advantage, the voting districts are re-drawn, illustrated in Figure 5. One voting district is a vertical strip to the right, with 100% of the votes for Party A. Party A wins the district. But the rest of the area is divided into 4 horizontal strips for the 4 districts. Now in each of these 4 districts, Party B wins by the ratio of 45-to-35, winning in all 4 districts. The result of gerrymandering is that the minority Party B wins 4 districts and the majority Party A wins only one. Packing is the approach when the party has the minority, packing the majority party in one or few districts, reducing their voting power in the rest.

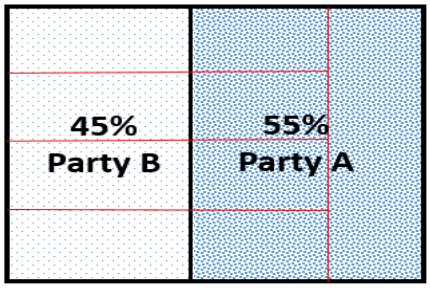

Fig.5 Packing to Limit the Majority.

4. GIS FOR GERRYMANDERING

The simplistic population distribution assumed in our hypothetical map makes it easy for us to explain and illustrate the two fundamental strategies of gerrymandering. In a real situation, it may not be so easy to form the voting districts to achieve cracking or packing. Theoretically, no algorithm exists to exhaustively search for all feasible solutions in gerrymandering.

A better approach is to use the GIS for interactive decision support. We need to first gather the data about where the voters are and which side they are likely to vote for. Such a map presented by the GIS will serve as a visual guide to see where the voters are located. The process is known in the GIS functionality as geocoding (Wu & Rathswohl 2010).

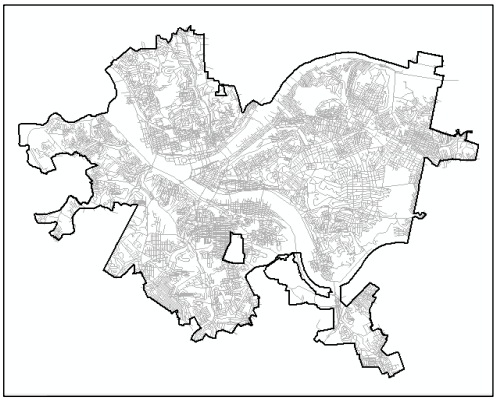

Fig.6 A City Street Map

To illustrate that in a simple way, suppose we have done the foot work of collecting the resident addresses of our political supporters who are to vote for us in a certain city. Figure 6 below shows a street map of the city.

Depending on the level of granularity desired for our map, it may be polygon geocoding just to identify the number of voters on each side within each area unit, or we may apply linear geocoding if we want to identify the point location of each voter (Goldberg 2016). For our illustration, we applied linear geocoding: from the collected addresses, the GIS produces a point map showing where each voter is located by the address. Figure 7 below shows the point map produced by geocoding superimposed on the street map.

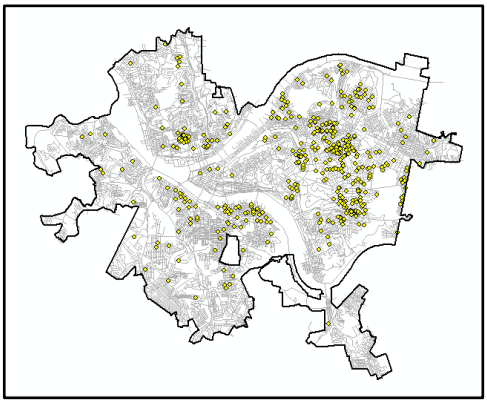

Fig.7 Geocoded Address Locations

Once we have the map to visualize where the voters are, we can use that as our guide to draw the desirable voting district boundaries. Suppose we want to make sure that one substantial group of our supporters in the north east will win in one district. We then draw on the map our desired district, as shown in Figure 8 below.

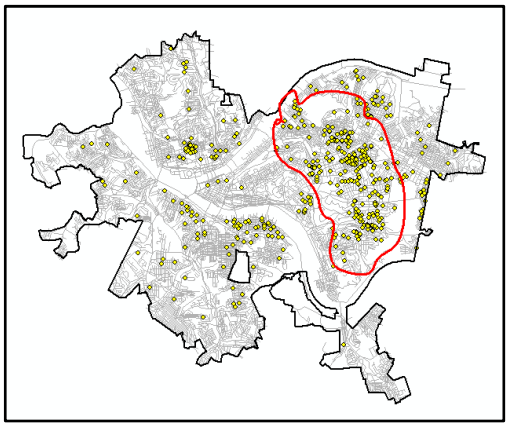

Fig.8 Drawing a voting district

For every district drawn, the functionality known as spatial join of the GIS allows us to immediately calculate the number of our supporters included there, and we can therefore project how likely we may win the voting district.

Suppose we recognize that our supporters do not constitute the majority and therefore need to at least win 3 districts. We can try drawing districts in various shapes, evaluating in each case, until we find the ones we desire. This trial and test approach guided by the visualized map becomes a very practicable way to obtain a robust solution for gerrymandering. Figure 9 shows our desired result of three districts, practicing extreme gerrymandering.

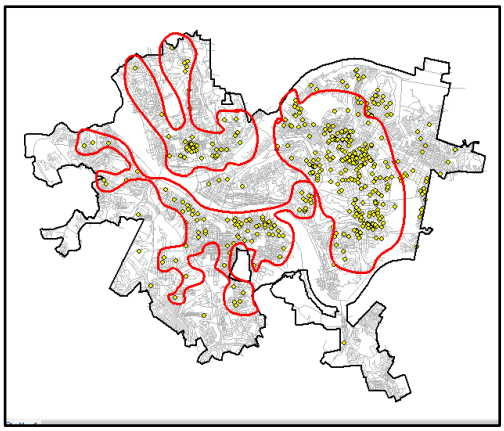

Fig.9 Gerrymandering result in 3 districts

Past attempts to fully automate the process using GIS were not successful (Li, Wang & Wang 2007; Yamada 2009; Siegel-Hawley 2013). There is significant difficulty in traversing or iterating the varieties of options in forming geometric shapes. Whereas using the GIS as an interactive tool for gerrymandering in the computer aided process has been much more promising. In the past decade, we have seen a rising number of cases of extreme gerrymandering (Forest 2018; Crane & Grove 2018).

5. TO PREVENT GERRYMANDERING

Political re-districting is necessary to facilitate for democratic voting when there are changes in the demographics of the voting population. In the past decade, however, gerrymandering becomes a way for politicians in power exercising their rights to deeply entrench themselves with political advantage. It becomes a difficult legal issue how to contest a re-districting map as gerrymandering. There

appears to be no easy solution. In this section, we will discuss the issues about how to prevent partisan gerrymandering.

The Electoral College by the founding fathers was originally meant for proportional representation in government. 1824 marked the significant shift to the Winner-Take-All rule in having districts for presidential as well as local elections (Mccarthy 2012). To outline our suggested approaches, this section will discuss the politics of the Winner-Take-All rule and use of non-partisan commission for political re-districting first, followed by the technical issues defining gerrymandering in terms of geometry, and the possible restriction in the use of voter information in re-districting. Finally, the state laws frame the regulation about political re-districting. We think that GIS researchers should work with legal professionals about this, and hopefully, GIS may be part of the solution.

The Winner-Take-All Rule

Gerrymandering is a possible tactic because of the winner-take-all rule. The rule lets the majority winner of a voting district to claim the entire electoral count of the district. Without that rule, gerrymandering will not matter since re-districting will not affect the total count of popular votes. The rule, however, is originally designed to allow a minority population to still have a voice in a democracy when there may be at least some districts within which the minority population becomes a majority. The Voters Rights Act of 1965 requires certain states to ensure minority representation, with at least one district formed based on race (US Department of Justice 1965). Ironically, that is gerrymandering in practice. In US presidential election, some states begin to consider dropping the winner-take-all rule to count only the total popular votes. On the other hand, swing states may then lose their relevance to the candidates if the Electoral College is designated to be proportional to the popular votes. That is for each state to consider. In similar ways, local governments may consider whether or not the winner-take-all rule should be adopted in their specific situations. In either case, political districting needs to preserve a channel for the minority.

Democracy ought to be based on government by proportional representation. However, given that the Winner-Take-All Rule cannot be abolished, we may then seek to revise it for appropriate adoption. It is worthwhile to note that currently in US presidential election, Maine and Nebraska both implement a kind of hybrid combining state wide and district vote counts (Mccarthy 2012).

Non-Partisan Commission

To avoid politicians in power exploiting the opportunity of re-districting by gerrymandering, often suggested is the solution to have a non-partisan commission in charge of re-districting so that there would be no intention to gain political advantage for either side. The idea is simple but the problem is the same. The political hot potato becomes: who should be in that commission? The political problem is only re-casted in a different venue. The Non-Partisan Commission approach is practiced in Florida, but it still has to deal with the requirements of the Voters Rights Act, including the creation of districts for minority representation. The current apportionment rule requires a population of roughly 750,000 per single member district, the practice would be even more difficult when population dispersion is not so ideally congruent, but more clustered than spread out, as in the case of Pennsylvania.

It is unlikely the approach will further involve research in using and understanding GIS, we will not go on with the discussion in this paper.

Recognizing Geometry in Gerrymandering

Founded strongly in theoretical computer science, the field of computational geometry has spawned many algorithms for programming to process geometry represented in digital data (Forrest 1971; Preparata & Shamos 1988). Much of GIS functionality has been built on the results of the research work. In the introduction of this paper, we noted that earlier attempts to automate the process of gerrymandering were not successful. Realizing that extreme gerrymandering is bad for democracy, many researchers then sought to develop programming algorithms to identify partisan gerrymandering so that it might be objectively disallowed. This paper also cited as references some of the research papers. Viewers of a district map may identify weird geometric shapes as evidence of politically motivated re-districting; such evidence is hardly objective proof, much less so in the court of law. Despite many creative esoteric ideas in research, a legal definition for gerrymandering in geometric and demographic terms remains an open question. In a more recent paper, two mathematicians Alexeev and Mixon (2018) summed up in much more definitive terms about how theoretically inconclusive we can expect the approach to be. The paper was titled "An Impossibility Theorem for Gerrymandering."

Perhaps the definitive algorithmic solution is not ready. We however would note that application

of artificial intelligence with machine learning to recognize gerrymandering has not yet been much explored.

Restrict the Use of Information

Gerrymandering requires the information about location of the voters as well as their voting inclination. How the information is used in re-districting may expose the intention to gain political advantage through gerrymandering. Legislature may therefore require the appropriate justification for re-districting to indicate that it preserves or promotes democracy. The exact details of such regulation however can become very tricky to articulate, particularly when we may also note the often significant co-relation between other demographic factors such as poverty and wealth, education level, racial and ethnic origin with voting inclination. The regulations will inevitably involve the geographical and analytical issues of population data. We believe this can be a more promising approach for our research so that GIS may be part of the solution to prevent gerrymandering.

State Laws

By U.S. constitution, the federal government will not interfere with how each state may govern the districting of voting population. Two recent Supreme Court cases in June (Maryland and North Carolina) affirmed that interpretation. It is therefore up to each state government to set up the policies for political re-districting. Gerrymandering has been legal since the state laws in general were not specifically written to identify and disallow it. Some states, such as Pennsylvania, may have law stipulating that political re-districting should promote democracy. The recent case of League of Women Voters v. Commonwealth of Pennsylvania (Grofman and Cervas 2018) may shed some light on the issues.

Nevertheless, it is time for GIS researchers to work with legal professionals on the topic, for a better democracy in the future.

6. SUMMARY AND CONCLUSION

Gerrymandering is the practice to manipulating voting district boundaries to gain political advantage in democratic voting. We presented a brief history of the term, and discussed two common approaches in gerrymandering: cracking and packing. Cracking is the approach to dilute the opponent's voting power by distributing the voters into more districts so that the opponent will not win any of the districts. Packing is the approach to concentrate the opponent's voting power into fewer districts so that opponent will win only those districts. Provided with the information where the voters are, the GIS readily presents the map to visually guide our search effort in re-districting. The GIS analytic functionalities can conveniently support trial and test each potential re-districting solution for extreme gerrymandering. To preserve and promote democracy, gerrymandering should be identified and disallowed. But it is quite a challenge to legally define it. Gerrymandering is possible because of the winner-take-all rule in counting votes. The winner-take-all rule is meant to promote democracy by preserving the voice of minority groups. We will have to take that into account. To disallow gerrymandering, the state government must now heed the work of legal professionals working with GIS researchers to identify and disallow gerrymandering.

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