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1. Abstract

Singapore's parliamentary system is a unique one where it has a multi-party parliamentary system with a representative democracy made up of the different constituencies divided by electoral boundaries. These electoral boundaries are decided upon and redrawn every election cycle. Due to the changing of electoral boundaries as well as the parliamentary misrepresentation of actual voter sentiment, the leading party in Singapore (the People's Action Party) has faced numerous accusations of gerrymandering. Our project aims to investigate the interesting effect of gerrymandering strategies on Singaporean electoral outcomes as well as measure the ways in which these strategies can be rendered more or less effective.

2. Introduction

2.1. Background

In representative democracies, gerrymandering refers to political manipulation of electoral district boundaries with the intent of creating an undue advantage for a party, group or socio-economic class within the constituency. This process can be achieved through a combination of gerrymandering strategies. For the sake of this project and model, we will be largely focussing on 2 strategies: packing and cracking.

2.2. Motivation

The Singaporean political scene has historically been consistently dominated by a single ruling party (the PAP), with a few opposition parties vying for parliamentary seats, the most notable being the Workers' Party. While voter sentiment on the ground in recent years has been moving to be in favour of these opposition parties (especially the Workers' Party), electoral outcomes and parliamentary seat allocations continue to reflect a highly disproportionate preference for the PAP. Throughout the years of elections, there have been accusations of gerrymandering in Singapore due to the constant redrawing of electoral boundaries and the dissolving of constituencies that return a high percentage of votes for parties other than the ruling one. This is further supported by the fact that every area of Singapore has seen at least one change in electoral boundaries since 1968 (Ricafort, n.d.).

Preventing the ruling party from using gerrymandering tactics during elections is a challenging task that requires a mass restructuring of Singapore's political landscape. Therefore,. it is important for voters and opposition parties to understand the ways in which gerrymandering can be rendered less or more effective, as well as the steps which can be taken to ensure that such tactics do not place them at a disproportionate disadvantage.

2.3. ABMS Justification

It is virtually impossible to observe how different gerrymandering strategies impact electoral outcomes in reality, as such a system is decided by the Elections Department, which is under the control of the Prime Minister's Office. Conducting a real life experiment on this would require testing variables that involve legislative change (eg. how electoral boundaries are drawn, how GRCs are allocated to the different constituencies) and actual election data under each of these scenarios. Thus, it is more practical to conduct a simulation which allows us to freely tweak these variables. ABMS specifically would be ideal for this experiment as it will be able to successfully capture the outcome of an election as an aggregate of each voter's choice - which is possibly influenced by agent-level factors such as their age, resident constituency, impression of each politician etc.

Thus, our project aims to use a voting and gerrymandering simulation model to dive deeper into various gerrymandering and Group Representation Constituency (GRC) allocation strategies to analyse how varying the flexibility of voters' decision making process affects the outcome of the gerrymandering process.

3. Literature Review

3.1 Redistricting: Drawing the Line[1]

This journal article proposed and investigated a class of ideas for evaluating whether a redistricting is truly representative or gerrymandered. To prove the realisticness of these evaluation techniques, the paper also assessed the extent to which political districting accurately represents the will of the people in the context of the congressional districts for the U.S. House of Representatives, with a particular focus on the state of North Carolina and its redistrictings since the 2010 census.

3 different types of measurement metrics were used in the course of this experiment, namely: the representativeness index, gerrymandering index and efficiency gap. The representativeness index is a measure of how "accurately representative" the results obtained by a given redistricting are, and the gerrymandering index is a measure of the degree to which gerrymandering tactics have been exacted on the districts. The efficiency gap quantifies the number of "wasted" votes each party cast.

According to the experiment results, the redistricting plans which produced the most gerrymandered districts (NC2012 and NC2016) also presented with the highest level of anomalous election outcomes (where the "reasonable" outcome used for comparison was derived with districts which are drawn in a nonpartisan fashion).

Building on the research presented in this paper, our project aims to apply a similar experiment to the unique Singaporen political system and evaluate the outcomes. Instead of only measuring and evaluating the historical redistricting done in Singapore, this model also simulates future gerrymandering as well as hypothetical situations (through manipulation of parameters) so as to present insights on the behaviours which agents (voters) can make in order to reduce the effectiveness of gerrymandering in misrepresenting parliamentary election outcomes.

3.2 NetLogo Model: RedistrictingPackNCrack[2]

The model randomly generates district maps and simulates voting and gerrymandering in a simple 2-party system. Election outcomes of each district are calculated using a first-past-the-post voting method, and the district maps are generated using standard districting rules - equal populations and contiguous districts. The population of districts are randomly distributed using an exponential distribution and the model employs a general clustering rule for placing Democrats and Republicans.

This model is a simple representation of a gerrymandering algorithm in the US context, and we built upon the methodology to adapt it to Singapore's context. Furthermore, while the initialisation of the values and distributions in this model were done based on some general rules, our model uses real life historical voting data to ensure a realistic representation.

In general, gerrymandering is a domain that is widely discussed and Singapore is also often used as an example (especially in recent years). Most model-based experimentation however, involves using US districting details and does not cover further experimentation on hypothetical scenarios regarding the tweaking of parameters to increase or decrease the effectiveness of different gerrymandering techniques.

4. Explored Phenomenon

In recent years, the Singapore public has begun to pivot in support of opposition parties (namely, the WP). However, the overall parliamentary election outcomes continue to result in a disproportionate majority of parliamentary seats being allocated to the PAP. Hence, the aim of our project is to simulate different gerrymandering scenarios and experiments and investigate certain agent behaviours that can reduce or increase the effectiveness of gerrymandering.

We hypothesise that voters who are more flexible in their voting thought process (ie. considering factors like party policies rather than purely basing their choices on their individual preferences for parties in a constituency) will render gerrymandering less effective.

5. Model Description

5.1. Model Layout

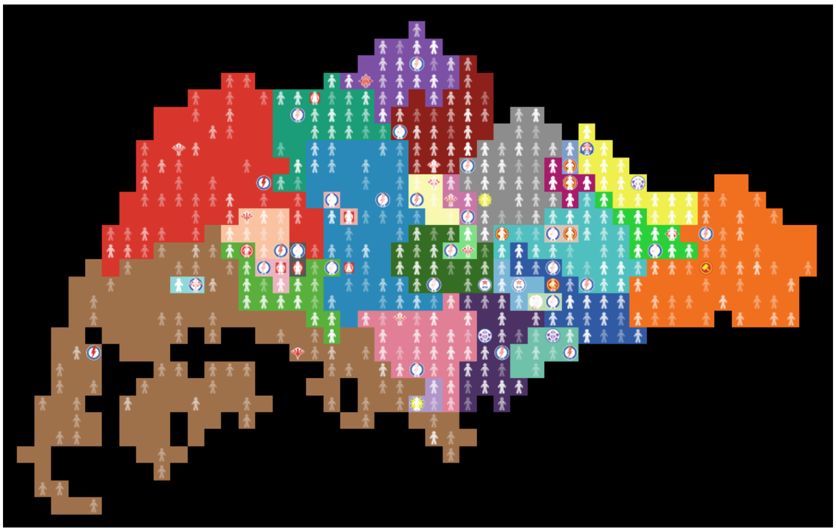

Figure 1. Model Layout

To explore the effect of gerrymandering on the voting landscape of Singapore, we must define an initial state. This is achieved by simulating the 2020 Singapore General Elections.

An approximation of Singapore's constituency map is created based on the latest electoral divisions by the Elections Department of Singapore. Each distinct constituency is marked with a unique colour, and the resolution of the map is decreased to improve performance and simplify the gerrymandering algorithms. The initial map contains a total of 31 unique patch colours (excluding black) representing the number of constituencies involved in the 2020 Singapore General Elections.

Hidden *party* agents are spawned to represent the political parties (e.g. PAP, WP) that ran during the election, and political teams (GRC / SMC representative(s)) are spawned on patches representing the respective constituencies they had ran in. Each team is linked to their party via a *membership* link.

To simulate voter behaviour, voter agents are spawned with a distribution based on the number of votes recorded in each constituency. There were a total of 2,554,000 eligible voters during the 2020 Singapore General Elections. To reduce the number of agents required, we define the VOTER_SCALE slider variable as the number of voters represented by each voter agent. By increasing VOTER_SCALE, the number of agents required in the simulation is reduced to a manageable degree. Each voter agent has a certain preference score towards each political team (elaborated in Section 6), stored in the *preference* link.

5.2. Process Overview

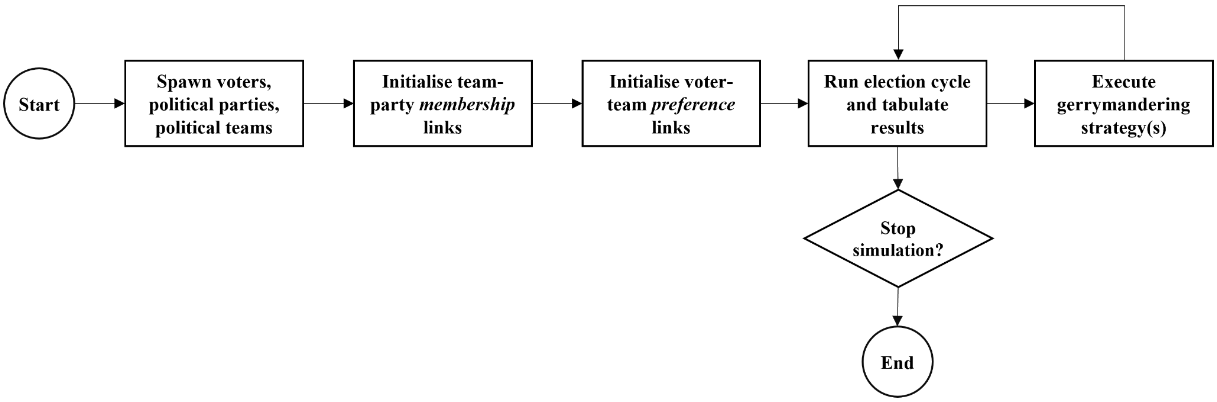

Figure 2. Overall Process Flow

After the model sets up the parties, constituencies, team, and voters, it enters the voting and gerrymandering process phase. Each voter votes for the political team in their constituency that they have the highest preference score towards. The votes are aggregated and tabulated per constituency, and the political team in each constituency with the highest number of votes wins the constituency, thereby gaining seat(s) for its members in parliament.

After a voting cycle, the model simulates gerrymandering by employing strategies based on the CRACKING_ENABLED and PACKING_ENABLED switch variables. Any changes in constituency boundaries are reflected on the map by changes in patch colours. The voting cycle is repeated after gerrymandering to observe the gradual effects of gerrymandering.

5.3. Implementation of Gerrymandering Strategies

5.3.1. Cracking

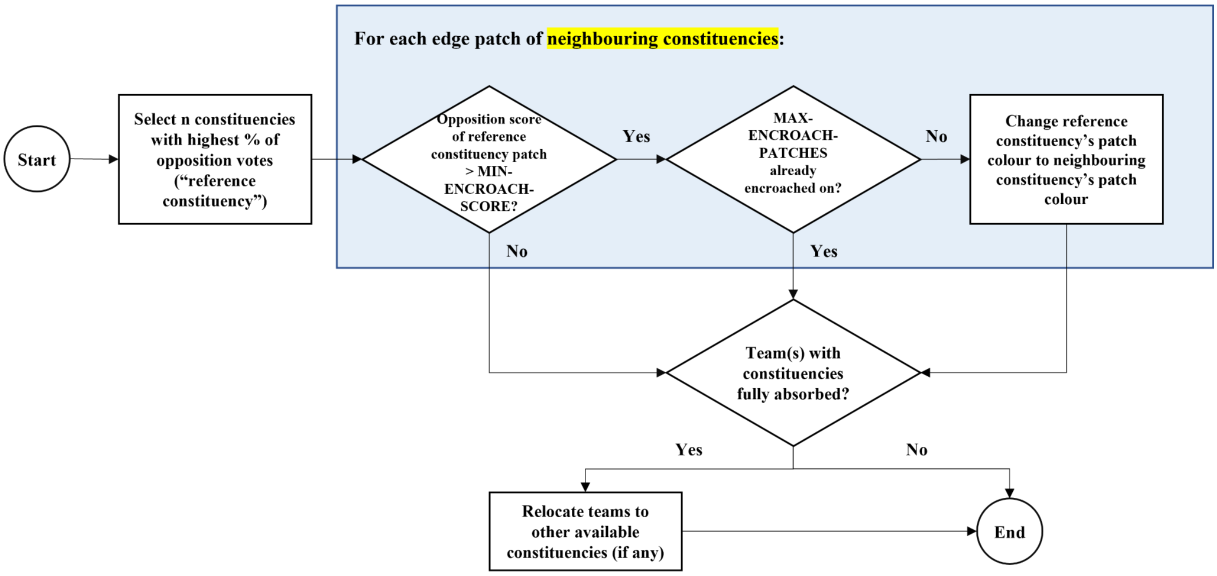

Figure 3. Cracking Process Flow

Cracking involves spreading voters that prefer a certain political party among many constituencies to deny them a sufficiently large voting bloc in any particular constituency. In our implementation, the best performing opposition constituencies have their edge patches encroached on by their neighbouring constituencies. This reduces the opposition voting strength in the encroached constituency, diluting them across the neighbouring constituencies. Instead of encroaching on every single patch available (as gerrymandering is usually done gradually and step-wise in reality), we define a minimum threshold (ENCROACH_THRESHOLD) for opposition voter strength before encroaching and an upper limit for the number of encroached patches per gerrymandering cycle MAX_ENCROACH_PATCHES.

If the opposition voter strength on all patches of an opposition-controlled constituency meets the minimum threshold and at least one voter agent is present on all patches of the encroached constituency, this implementation will eventually completely absorb (and thus dissolve) the constituency, thereby removing territory that was once helmed by opposition parties.

5.3.2. Packing

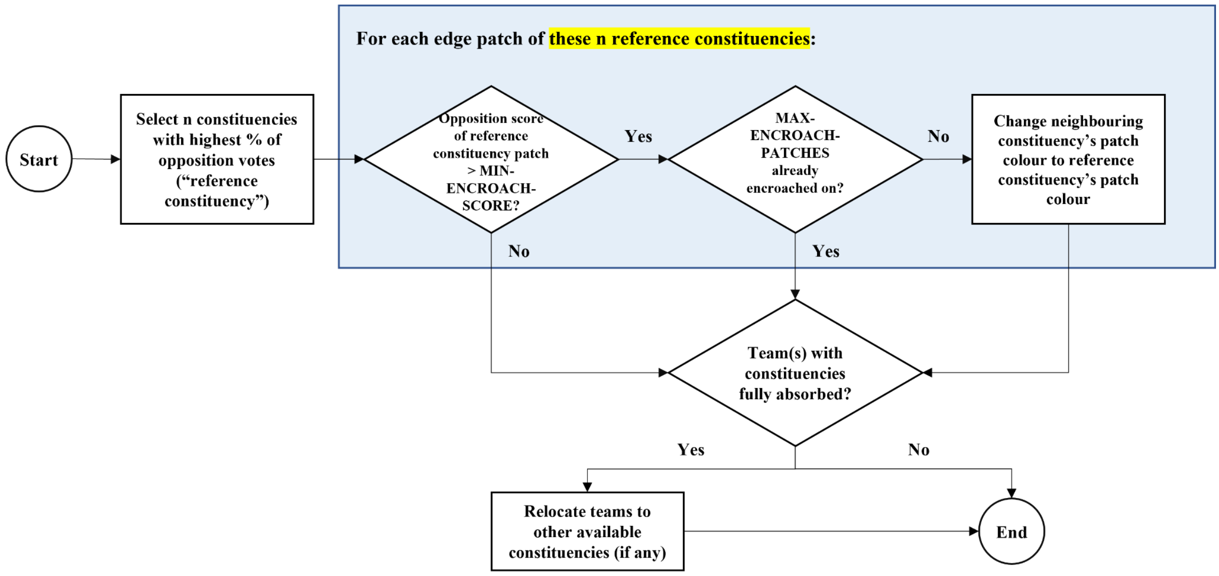

Figure 4. Packing Process Flow

Packing involves concentrating many voters of one type into a single constituency to reduce their influence in other constituencies. Our implementation of packing is similar to that of cracking, with the exception that the top performing constituency(s) encroach on its neighbours. Given that opposition voters already form the majority in these constituencies, absorbing other patches with a high concentration of opposition voters has a potential positive effect on the ruling party (reducing opposition vote strength in neighbouring constituencies) but at most a neutral effect on the opposition party (e.g. a 60% vs 70% opposition-favoured result in its constituency still nets them the same number of parliamentary seats). Similar encroachment constraints were added to packing as well.

6. Description of Parameters

Parameter	Value(s) Used	Justification
Preference scores between voters and political teams	Normal distribution with bias based on voting results in 2020 General Election	Voter preferences are based on a multitude of factors that cannot be easily modelled e.g. ideology, peer pressure, alignment to party platforms. We make the assumption that these preferences can be represented as a normally distributed one-dimensional score, with a bias based on the actual election results.
VOTER_RANDOM_MEAN The mean of the randomness factor in each voter's preference for any team	5 (default)	The bias mentioned above for preference scores ranges from 5 to 10. The mean of the randomness factor in a voter's preference score is set to 5 by default to provide a 1:1 ratio between preference and randomness in the worst case.
VOTER_RANDOM_STDEV The standard deviation of the randomness factor in each voter's preference for any team	1	By default, we keep the variability of a voter's preference low to provide consistent simulated election results that are close to observed election results.

VOTER_FLEX_STDEV The standard deviation of the flexibility of each voter	1	For each election, we also introduce a random flexibility adjustment that increases or decreases a voter's preference for any party team. We make the assumption that this models the variations in preferences per election based on changes in party platform, policy, and candidate appeal.
Number of voters in each constituency	Number of voters in each constituency in 2020 General Election	We initialise the model with the electoral boundaries from 2020. Matching the voters to each constituency provides the most accurate simulation of the election results.
Maximum number of encroached patches per gerrymandered constituency per cycle	1	Given that one voter agent represents a sizeable number of voters, this prevents the case where a gerrymandering cycle unrealistically affects too many voters and sways election results too sharply.
VOTER_SCALE	1000	Reducing the number of voter agents allows for an improvement in performance at the cost of reducing the granularity of voter spread.

Table 1. Values and Justification for each Parameter

7. Experiments

Unless specified otherwise, all experiments assume the parameters defined in Section 6. Each test configuration is stopped after 25 iterations as it provides a better estimate of the short term performance. All test configurations are repeated 5 times before the results are averaged.

7.1. Varying Combinations of Gerrymandering Strategies

We aim to discover the effectiveness of gerrymandering strategies when used in isolation and in combination with one another in the context of Singapore's political landscape.

7.1.1. Experiment Setup

The following combinations of strategies were tested over 25 gerrymandering cycles.

CRACKING_ENABLED	PACKING_ENABLED
true	true
true	false
false	true

Table 2. Combinations of Gerrymandering Strategies Used

7.1.2. Experiment Results

Testing Configuration	Seats Won	Total Votes	Votes Received (+) / Lost (-) due to Unavailable First Choice
Control CRACKING_ENABLED = false PACKING_ENABLED = false	PAP: 83.0 WP: 10.0 PSP: 0.0	PAP: 1,559,600 WP: 285,600 PSP: 262,400	PAP: -400 WP: -400 PSP: +400
CRACKING_ENABLED = true PACKING_ENABLED = true	PAP: 88.2 WP: 2.2 PSP: 0.0	PAP: 1,669,600 WP: 217,200 PSP: 249,600	PAP: +109,600 WP: -68,800 PSP: -12,400

CRACKING_ENABLED = true PACKING_ENABLED = false	PAP: 90.2 WP: 1.6 PSP: 1.2	PAP: 1,643,200 WP: 241,600 PSP: 247,200	PAP: +83,200 WP: -44,400 PSP: -14,800
CRACKING_ENABLED = false PACKING_ENABLED = true	PAP: 85.4 WP: 3.2 PSP: 0.0	PAP: 1,636,800 WP: 253,200 PSP: 298,000	PAP: +76,800 WP: -32,800 PSP: +36,000

Table 3. Experiment Results of Varying Gerrymandering Strategies

7.2. Varying Voter Flexibility

We also want to learn if there are any voting strategies that can be employed to reduce the effectiveness of gerrymandering. One of the strategies in reducing the effectiveness of gerrymandering in the face of an overwhelming majority is to vote with more flexibility i.e. avoid strictly voting for the most preferred party. To simulate this behaviour, we vary the parameters for voter preferences and flexibility.

To reduce the chance of constituencies merging and effectively reducing the total number of seats, we employ the cracking strategy only for each test configuration.

7.2.1. Experiment Setup

The following combinations of strategies were tested over 25 gerrymandering cycles.

- Increasing VOTER_RANDOM_MEAN reduces the effect of the voter preferences bias factor.
- Increasing VOTER_RANDOM_STDEV makes voters more likely to sway their initial impression of party teams.
- Increasing VOTER_FLEX_STDEV adds more noise to each voting decision.

VOTER_RANDOM_MEAN	VOTER_RANDOM_STDEV	VOTER_FLEX_STDEV
5	1	1
5	5	1
10	1	1
10	5	1
5	5	5
5	5	10

Table 4. Combinations of Voter Flexibility Used

7.2.2. Experiment Results

Testing Configuration	Seats Won	Total Votes	Votes Received (+) / Lost (-) due to Unavailable First Choice
VOTER_RANDOM_MEAN = 5 VOTER_RANDOM_STDEV = 1 VOTER_FLEX_STDEV = 1	PAP: 90.0 WP: 3.0 PSP: 0.0	PAP: 1,628,800 WP: 245,200 PSP: 248,400	PAP: +68,800 WP: -40,800 PSP: -13,600
VOTER_RANDOM_MEAN = 5 VOTER_RANDOM_STDEV = 5 VOTER_FLEX_STDEV = 1	PAP: 51.4 WP: 4.4 PSP: 2.2	PAP: 1,003,200 WP: 186,800 PSP: 211,200	PAP: -747,200 WP: -22,400 PSP: -56,000
VOTER_RANDOM_MEAN = 10 VOTER_RANDOM_STDEV = 1 VOTER_FLEX_STDEV = 1	PAP: 89.0 WP: 4.0 PSP: 0.0	PAP: 1,635,200 WP: 254,000 PSP: 248,800	PAP: +75,200 WP: -32,000 PSP: -13,200
VOTER_RANDOM_MEAN = 10	PAP: 81.6	PAP: 1,498,800	PAP: -253,600

VOTER_RANDOM_STDEV = 5 VOTER_FLEX_STDEV = 1	WP: 6.0 PSP: 1.8	WP: 265,600 PSP: 268,400	WP: 65,200 PSP: 15,600

Table 5. Experiment Results of Varying Voter Flexibility

8. Verification and Validation of Model

8.1 Verification of Ground Truth

In order to validate the reliability of our model, we conducted control experiments to determine if the results obtained from the simulation were similar to that of the real world. Indeed, the outcome of the control election reflects the actual results of the 2020 General Elections. This shows that our model implementation, as well as assumptions about voters and political teams, were reasonably grounded in reality.

9. Conclusion

The results of our model experimentation support our hypothesis; if voters take into consideration other factors in making a vote choice (ie. policies, promises etc) rather than only focussing on their individual preference for politicians or parties, gerrymandering tactics would have a much lower effect on the electoral outcomes of Singapore's elections.

In conclusion, given this discovery, the efficacy of gerrymandering tactics like packing and cracking can be mitigated by individual voter choices. More specifically, the broadness of variables which voters take into consideration when casting their electoral votes affects the predictability of their current and future votes, and hence makes gerrymandering more accurate and effective. However, in the face of an overwhelming difference in the representation of incumbent and opposition parties (as is the case in Singapore), we acknowledge that the effect of individual voter choices is limited, and a broader top-down approach is needed to reform the electoral process for fairer representation.

10. Future Work

10.1 Representation of Voter Preference

However, we acknowledge that the estimation of voter preferences as a one-dimensional value is severely limited. Given more resources and time, we may want to develop a multi-dimensional representation of preference and use vector closeness as a better measure of a voter's alignment with a party.

10.2 Team Allocation of Political Parties

We could explore using a game theory approach to have each political party determine team allocation strategies that net them the most optimal outcome. For example, whether to send their strongest team to contest a losing constituency, or to concede that constituency to the opposition entirely.

11. Acknowledgements

Prof Cheng Shih-Fen for his guidance.

12. References

[1] Bangia, S., Graves, C. V., Herschlag, G., Han, S. K., Luo, J., Mattingly, J. C., & Ravier, R. (2017, May). *Redistricting: Drawing the Line*. Cornell University. https://arxiv.org/abs/1704.03360

[2] *NetLogo User Community Models: RedistrictingPackNCrack*. (n.d.). NetLogo. Retrieved April 20, 2022, from http://ccl.northwestern.edu/netlogo/models/community/redistrictingPackNCrack

[3] Ricafort, J. (n.d.). *Almost all of Singapore has seen at least one constituency change since 1965*. The Straits Times. Retrieved April 20, 2022, from https://www.straitstimes.com/multimedia/graphics/2020/06/singapore-general-election-ge2020-constituency-changes/index.html