MPhil Research Proposal

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The Proposed Title

New algorithms for effectively visualising Australian spatio-temporal disease data.

The Proposed Supervisory Team

Principal Supervisor: Professor Kerrie Mengersen; Science and Engineering Faculty, School of Mathematical Sciences

Associate Supervisor: Dr Earl Duncan; Science and Engineering Faculty, School of Mathematical Sciences

Non QUT Associate Supervisor: Professor Dianne Cook; Econometrics & Business Statistics Faculty, Monash University.

Background and Literature Review

Introductory Statement

Visualising data has helped to understand problems in many scientific fields. A classic example in disease data is the map of London, made by Dr John Snow, pinpointing water pump locations among cholera occurrences, that made the case for the cause being contaminated water. A nice discussion of this can be found by Tufte et al. (1998).

Disease data is often aggregated by political areas. One reason for this is privacy, another the responsibility on the political entity to respond. The typical visualisation for aggregated spatial data is a choropleth map, where areas are coloured by the numerical value. Maps contribute to understanding spatial distributions of disease occurrence, and locating disease clusters. The problem is, especially for Australia, the spatial distribution is obscured by the prevalence of vastly different sized areas. More effective visualisations are needed to better represent the spatial distribution, with a focus on Australian disease mapping. The work is motivated by the Cancer Atlas of Australia, which presents the spatial patterns of many cancers in Australia.

Literature Review

Statistical maps of geographic areas

An alternative to a choropleth map for visualising spatial data is a cartogram. Waldo Tobler (2004) explores the progression from choropleth maps to cartograms and considers the situations which favour either display. Choropleth methods are geographically accurate maps, and represent data using colour, transparency and other methods. Geographical areas maintain their shape, size and location. This preserves spatial relationships, and neighbours can be reasonably considered related. Cartograms are used to focus on the spatial distribution within the geographically related data. They transform the map, to make the size of the geographic shape reflect the measured data, whilst maintaining the relative geographic position of the area. Priority is on the spatial distributions of the statistic.

Cartograms have been implemented since 1851 (Tobler 2004). Sabrina Nusrat and Stephen G. Kobourov (2018) recognise four cartogram types: contiguous, non-contiguous, Dorling and rectangle. These methods change the size of areas relative to a statistic. Cartogram methods represent regions using rectangles (Kreveld and Speckmann 2007) or circles (Dorling 2012) for Dorling cartograms. Consistent shapes are used, but sizes differ to represent a statistic. The term 'mosaic cartograms' was introduced (Cano et al. 2015) to describe an alternative cartogram display. Carr, Olsen and White's (Carr, Olsen, and White 1992) 'hexagon mosaic map' discussion cites Carr's previous work finding hexagons provide visual appeal and 'representational accuracy'. The authors credit nature for the concept of tessellated hexagons tiles. They provide as little disruption as possible to the area adjacencies, especially at lower resolutions where smaller hexagons capture more geographical details.

Daniel Dorling's cartograms allow one circle for each area (Dorling 2012). It maintains the spatial distribution for each area by 'touching as many others that it originally neighboured as possible while touching as few as possible that it did not.' Maintaining spatial relationships is necessary to visually analyse spatial distributions, especially for the visual analysis of small geographic areas. Dorling mentions choropleth geographical maps of Australia and Canada are particularly affected by the following problem: "on any traditional map of an urbanised country, the majority of political constituencies are literally not visible to the naked eye" (Dorling 2012). Journalist Nick Evershed uses the headline "Australian electorates vary greatly in size, which makes it extremely difficult to present election results geographically. We've come up with a solution" (2013). This prefaces a solution to the issue. As sizes of the electorates range between 30 and 1,587,758 sq km a cartogram display was considered. Citing the prevalence of cartograms in the US media, however in the context of Australia most algorithms produced an unrecognisable shape. Evershed points to 150hexagons.com as a step toward a display that is more representative and emphasises each electorate equally. This inspired Evershed and Dance's interactive map (Evershed and Dance 2013) where each electorate is represented by a displaced circle, that are sized according the population. It also features an underlaid map of Australian geographies to aid interpretation.

Evaluating alternative representations

The cartogram methods differ based on the preservation of shape, topography and the statistical accuracy. The effectiveness of the methods have been contrasted (Nusrat, Alam, and Kobourov 2018) and the algorithms have been evaluated in terms of time and error, and the visualisation subject preferences. Xiaoyue Cheng (2015) recognises that methods must be supplemented with

algorithms, yet there are few available. The author provides a shiny application that helps to both create and evaluate a contiguous cartogram. These measures may now be supplemented with a new approach.

Statistical inference for graphics was introduced by Buja et al. (2009), to determine if patterns that appear in visualisations are 'really there', and the methods were validated by Majumder, Hofmann, and Cook (2013). Wickham et al. (2010) introduced the ideas to the information visualisation community. Their approach has been applied to common graphics, and presents the opportunity to measure effectiveness of a new graphic in comparison to established visualisation methods (Hofmann et al. 2012). Graphical Inference is a modern statistical procedure to visually recognise structure in data.

The question: "Is there a spatial trend?" is historically associated with choropleth maps (Wickham et al. 2010). Using the visual inference approach called a lineup, an example is shown that examines spatial trend choropleth map. The map of the data is displayed in a field of null plots, constructed without a spatial trend. These lineup tests can be used to objectively test for a trend, pattern or relationship in the true data, if the data plot is detectably different from the null plots in the line-up.

Adapting this approach could be used to test the effectiveness of the choropleth map, against an alternative graphic. By contrasting the results of the choropleth and alternatives, that present the same true data in line-ups of null plots. This contrast can be used to statistically test the effectiveness of the visual display in communicating spatial data, following the approach by Hofmann et al. (2012). The R package, nullabor (Wickham et al. 2018), is able to create line-ups of plots that can be used in this testing.

This study also endorses Amazon Mechanical Turk (2008) as a source of capable workers to view the line-ups as an "uninvolved observer" is necessary to validate the design.

Enchancing applications using animations

Choropleth maps are regularly used in the United States, most recently to present results and race calls from The Associated Press for the mid-term elections (Almukhtar et al. 2018) along with the 2017 primary elections (Kimelman, Chaumont, and Swartz 2017).

Applications of cartograms (Nusrat and Kobourov 2016) have been seen in social, political and epidemiological contexts. The Christopher Kocmoud, and Donald House, are cited stating 'cartogram can better show the distribution' (Kocmoud and House 1998) when considering the spread of a disease. The move toward alternative mapping techniques has progressed with the accessibility of animations. Especially in the statistical computing community which has recently been improved with the development of gganimate (Pedersen and Robinson 2017).

Projecting data into the recognisable form of the geography, and then transforming to an alternative representation allows deeper understanding of the data. Thomas Lin Pedersen (Pedersen 2018) suggests animating visualisations as it 'demands attention'. This is especially convenient to direct attention, as animations do not assume captive audiences, instead inform by narrating the intended message communicated by the visualisation.

Research Problem (e.g. aims, questions and/or hypotheses)

The Australian population has congregated in the capital cities, and significant cities in each state. This pattern has resulted in very dense population centres, and sparsely populated rural areas. Population groups have been created at many levels, to approximate equal population in each group, the geographical bounds now used statistically are extremely heterogeneous. The size of the states, the largest geographical division, also vary greatly, and this is feature persists for all ABS Structures and Non ABS Structures. This relationship between the Australian population and geographical area results in a wide distribution of the map space. Using most mapping techniques to get a broad perspective of Australia can be misleading, when the use of geographical areas misrepresents the spatial distribution of a dataset.

A possible alternative will represent each area equally on the map space. The use of colour, transparency and symbols will still available for variables.

Aims

1. *Algorithm for hexmapping Australia:* The algorithm will take geospatial areas in the form of polygons, and create an alternative graphical display of the variable that is believed to be spatially distributed.

2. *Test the effectiveness of the hexmap relative to the choropleth map for providing a more accurate reading of spatial distribution for Australia:* The display produced by the algorithm will be contrasted with the traditional choropleth map, applying the same colour and transparency methods to represent the data values. The maps will be presented in the form of experiments, to test the effectiveness by asking for interpretation of spatial distributions.

3. *Communicating the relationship between the hexmap and choropleth map through animation algorithm:* Finally, we recognise the value of presenting users with standard maps that are familiar, if we prove the belief that the alternative method enhances interpretation of the spatial distribution we will aim to maximise the benefits of both. The use of animations will allow us to control how people transform a recognisable map of Australia, or the cities within, into a more sound map for inference. Animation has been used for many years, and is gaining popularity as access to computing power is increasing the amount of applications.

Program and Design of the Research Investigation

Objectives, Methodology and Research Plan

Aim 1: Algorithm for hexmapping Australia

Produce alternative mapping strategies. While there are visualisations available for spatial data, we can benefit by exploring and creating new displays. During the past few months work has progressed that contributes to this first aim. We have been able to achieve a working algorithm for a hexmap of Australia (Kobakian and Cook 2018). This algorithm takes a set of polygons and creates a map of tessellated hexagons, representing a single geographical area with a single hexagon. They are arranged to replicate spatial relationships of areas in each city.

The following tasks have been achieved:

1. Began SugaRbag package; to organise and document functions that implement the hexmap algorithm
     - ensure no null geometries (named areas with no location)
     - project data in Australian standard projection
     - automate hexagon size
     - find centroids (central point) of projected polygons
     - include capital cities as a data set
     - included simplified data for SA2 in 2011 and 2016
     - allowed data to be provided in different formats e.g.. Rda or ESRI
     - filtering grid points, ensures at least one point is returned
     - implemented algebraic method to filter grid for a 60 degree slice of a circle around centroid
     - allow users to provide their own focal points e.g.. centre of Australia, regional cities
     - check buffer distance is appropriate
     - vastly improved buffer grid, rolling average minimum and maximum of the centroids in Australian border
     - output the hexmap allocations and shape information
     - show user the progression through steps
     - create faceted maps using geofacet
     - create plots of geography and hexagons

To extend Aim 1, we plan to incorporate repelling and attraction mechanisms inspired by Xiaoyue Cheng (2015). This could allow rural areas to bunch together and allow easier comparison of colours or symbols.

Aim 2: Testing the effectiveness of the hexmap relative to the choropleth map

To test the effectiveness of the alternative mapping techniques, we will produce an experiment hosted on Amazon's (2008) Mechanical Turk. The 'concept of a 'null distribution of plots' as the analogue of the null distribution of tests statistics' (Wickham et al. 2010) using 'the line-up' protocol Buja suggests.

We have the opportunity to treat a visualisation as a statistic, the visualisations may be compared just as numerical features of models or data summaries can. The alternative maps should be implemented if methods show statistical distributions are present, and not noticed using geographical maps.

The experiment will form a survey of line-up plots of Australian maps. Each participant will see a random selection of the control combinations, they will see both the choropleth map and the hex map.

To distinguish the effectiveness of the maps, we will contrast the participant's recognition of the spatial distributions when displayed in each map type. A statistically significant difference in the group means will be computed in R (2018), a software for statistical analysis.

We propose the following experiment:

Factors:

1. Plot Type:

- Hex map and Choropleth map

2. Distribution of estimates:

- Normal
- Skewed: right; similar to the Cancer Atlas data
- Clustered

3. Spatial dependence:

- Random: values of spatial areas are randomly pulled from relevant distribution
- Spatial Dependence: values of spatial areas are randomly pulled from a range surrounding their neighbours, within the relevant distribution

Replications: control combinations, where the replications are randomised draws of data

Randomisation: Participants will be shown a selection of the line-ups.

The entire experiment will be replicated with new simulated data sets and a different set of participants.

Aim 3: Communicating the relationship between the hexmap and choropleth map: animation algorithm

Animations will be created using the gganimate (Pedersen and Robinson 2017) package, implemented in the R (2018) statistical software language and environment.

The animations will transform the geographic display of Australia to the alternative map. It will draw attention to the changes in size of the areas.

Resources and Funding Required

A request for funding will be submitted to undertake the line-up experiment on Amazon Mechanical Turk. We suggest 90 respondents at $5 each.

We will utilise the currently available equipment. A self provided laptop with access to the open source R software. We acknowledge the funding of the Research Training Program (RTP), ACEMS for supporting the author.

Data resources will also be provided by the Australian Cancer Atlas online download tool.

Timeline for Completion of the Program

1. *Algorithm for hexmapping Australia*
2. *Testing the effectiveness of the hexmap relative to the choropleth map*
3. *Communicating the relationship between the hexmap and choropleth map: animation algorithm*
   A. Addition activities: coursework units, deadlines, thesis preparation

(Expected) Months	(Expected) Time	Task	Status
Semester 2 2018		- (A) FIT9133: Programming fundamentals in Python: Semester 2, Monash University	
June - August	**3 months**	- (1) Allocation of polygon area centroids to hex map grid centroids	Completed
	1 week	- (A) useR!2018 Conference	
		- (1) Arrangement of centroids to allocate in order	
		- (1) Incorporate capital city relationships and directional centroid allocations	
September	**1 month**	- (1) Tidy to allow provision of polygons	Planned
October - November	**2 months**	- (1) Automate tuning for size of hexagons	
December	**1 month**	- (A) Prepare thesis chapter for submission	
January - February	**2 month**	- (2) Preparation of survey questions	Planned

(Expected) Months	(Expected) Time	Task	Status
Semester 1 2019		- (A) ETC4541: Bayesian time series econometrics: Semester 1, Monash University	
March	**1 month**	- (2) Execution of experiment	
April	**1 month**	- (A) Annual Progress Report	
May - June	**2 months**	- (2) Data Analysis	
July	**1 month**	- (A) Prepare thesis chapter for submission	

(Expected) Months	(Expected) Time	Task	Status
Semester 2 2019			
August - September	**2 months**	- (3) Apply transformation algorithm, polygons to hexagons	Planned
October	**1 month**	- (3) Prepare thesis chapter for submission	
November	**1 month**	- (A) Complete masters thesis	

Reference List

Almukhtar, Sarah, Mike Andre, Wilson Andrews, Matthew Bloch, and Jeremy Bowers. 2018. "House Election Results: Democrats Take Control." *The New York Times*, November. A. G. Sulzberger. https://www.nytimes.com/interactive/2018/11/06/us/elections/results-house-elections.html.

Amazon. 2008. "Mechanical Turk."

Buja, Andreas, Dianne Cook, Heike Hofmann, Michael Lawrence, Eun-Kyung Lee, Deborah F. Swayne, and Hadley Wickham. 2009. "Statistical Inference for Exploratory Data Analysis and Model Diagnostics." *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 367 (1906). The Royal Society: 4361–83. https://doi.org/10.1098/rsta.2009.0120.

Cano, R. G., K. Buchin, T. Castermans, A. Pieterse, W. Sonke, and B. Speckmann. 2015. "Mosaic Drawings and Cartograms." *Computer Graphics Forum* 34 (3): 361–70.

Carr, D. B, A. R. Olsen, and D. White. 1992. "Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data." *Cartography and Geographic Information Systems* 19 (4): 228–36.

Cheng, Xiaoyue. 2015. "Interactive Visualization for Missing Values, Time Series, and Areal Data." Iowa State University.

Dorling, Daniel. 2012. *The Visualisation of Spatial Social Structure.* John Wiley & Sons Ltd.

Evershed, Nick. 2013. "Building a Better Election Map." *The Guardian*, September. Guardian Media Group. https://www.theguardian.com/world/datablog/2013/sep/06/better-election-results-map.

Evershed, Nick, and Gabriel Dance. 2013. "Australian Election Results: Interactive Map." *The Guardian*, September. Guardian Media Group. https://www.theguardian.com/world/datablog/interactive/2013/sep/06/australian-election-results-map.

Hofmann, H., L. Follett, M. Majumder, and D. Cook. 2012. "Graphical Tests for Power Comparison of Competing Designs." *IEEE Transactions on Visualization and Computer Graphics* 18 (12): 2441–8. https://doi.org/10.1109/TVCG.2012.230.

Kimelman, Jeremia, Kriss Chaumont, and Samantha Swartz. 2017. "Mapping the Race to Control the House." *Nbcnews*, March. NBCUniversal. https://www.nbcnews.com/politics/elections/mapping-race-control-house-n906076.

Kobakian, Stephanie, and Dianne Cook. 2018. "SugaRbag." *GitHub Repository*. https://github.com/srkobakian/sugaRbag; GitHub.

Kocmoud, Christopher, and Donald House. 1998. "A Constraint-Based Approach to Constructing Continuous Cartograms," January.

Kreveld, M. van, and B. Speckmann. 2007. "On Rectangular Cartograms." *Computational Geometry: Theory and Applications* 37 (3): 175–87. https://doi.org/10.1016/j.comgeo.2006.06.002.

Majumder, Mahbubul, Heike Hofmann, and Dianne Cook. 2013. "Validation of Visual Statistical Inference, Applied to Linear Models." *Journal of the American Statistical Association* 108 (503). Taylor & Francis: 942–56. https://doi.org/10.1080/01621459.2013.808157.

Nusrat, Sabrina, and Stephen G. Kobourov. 2016. "The State of the Art in Cartograms." *Comput. Graph. Forum* 35: 619–42.

Nusrat, S., M. J. Alam, and S. Kobourov. 2018. "Evaluating Cartogram Effectiveness." *IEEE Transactions on Visualization and Computer Graphics* 24 (2): 1077–90. https://doi.org/10.1109/TVCG.2016.2642109.

Pedersen, Thomas Lin. 2018. "The Grammar of Animation." 2018. https://youtu.be/21ZWDrTukEs.

Pedersen, Thomas Lin, and David Robinson. 2017. *Gganimate: A Grammar of Animated Graphics.* http://github.com/thomasp85/gganimate.

R Core Team. 2018. *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Tobler, Waldo. 2004. "Thirty Five Years of Computer Cartograms." *Annals of the Association of American Geographers* 94 (1). Routledge: 58–73. https://doi.org/10.1111/j.1467-8306.2004.09401004.x.

Tufte, Edward R, Susan R McKay, Wolfgang Christian, and James R Matey. 1998. *Visual Explanations: Images and Quantities, Evidence and Narrative.* AIP.

Wickham, Hadley, Niladri Roy Chowdhury, Di Cook, and Heike Hofmann. 2018. *Nullabor: Tools for Graphical Inference.* https://CRAN.R-project.org/package=nullabor.

Wickham, H., D. Cook, H. Hofmann, and A. Buja. 2010. "Graphical Inference for Infovis." *IEEE Transactions on Visualization and Computer Graphics* 16 (6): 973–79. https://doi.org/10.1109/TVCG.2010.161.

Appendix

The sugaRbag package contains all code for the construction of the alternative map. The algorithm is broke into multiple functions, and will be supported by vignettes that explain how to use sugaRbag to create an alternative map.

https://github.com/srkobakian/sugaRbag

Coursework

In all cases, your required coursework needs to be based upon a research degree skills audit and a written plan briefly setting out the educational outcomes expected from the coursework. This coursework is planned together with your Supervisors to contribute and provide structure to your overall program of research.

Courses undertaken at QUT: IFN001 Advanced Information Research Skills (AIRS)

Courses undertaken via cross institutional study at Monash University: FIT 9133 Programming fundamentals in Python Completed at Monash Univeristy, Semester 2, 2018.

ETC 4541 Bayesian time series econometrics To be completed at Monash Univeristy, Semester 1, 2019.