Empirical Agent-Based Modelling for exploring Intergroup Contact in a Segregated Society

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Empirical Agent-Based Modelling for exploring Intergroup Contact in a Segregated Society

Huck J.J.[1*], Whyatt, J.D.[2], Dixon, J.[3], Davies, G.[2], Sturgeon, B.[4], Hocking B. Jarman, N.[5], Bryan, D.[4],

[1] MCGIS, Department of Geography, The University of Manchester
[2] Lancaster Environment Centre, Lancaster University
[3] Department of Psychology, Open University
[4] School of History, Anthropology, Philosophy and Politics
[5] Peace Direct, London

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Summary

Agent-based modelling has a long history of application in the study of segregation, but is rarely deployed beyond the examination of residential segregation. This study leverages multiple datasets: including census, survey, PGIS and GPS traces; in order to create an empirical agent-based model for the exploration of mobility practices between segregated communities in Belfast (Northern Ireland). In doing so, we are able to conduct novel examinations into the impact of day-to-day mobility choices upon intergroup attitudes and activity-space segregation; with policy implications for understanding and combatting segregation in cities around the world.

KEYWORDS: Segregation, Bayesian, Agent Based Modelling, Mobility, Contact Hypothesis

1. Introduction

In the field of segregation studies, research has shown that positive contact between segregated communities can improve intergroup relations (Dixon et al., 2019). In Northern Ireland, for example, studies have found that positive interactions between segregated groups of Catholics (*'nationalists'*) and Protestants (*'unionists'*) are associated with improved sectarian attitudes, forgiveness, and civic engagement (e.g., Hewstone et al., 2006; McKeown & Taylor, 2017; Paolini, et al., 2004). Dixon et al. (2019) demonstrated the importance of individuals' day-to-day mobility choices in understanding this effect, as 'preferential segregation' can act to limit opportunities for positive contact and therefore the associated social benefits. Similarly, Huck et al. (2019) highlighted the importance of physical infrastructure in the creation of contact opportunities, including through increased evidence of 'sharing' in so-called '*non-places*', such as shopping malls and supermarkets, which are defined by their homogeneity and focus on consumption (see Auge, 2008).

This research seeks to apply an empirical agent-based modelling (ABM) approach to examining the implications of both of these findings. Using a selection of datasets describing community behaviours and perceptions in Belfast (Northern Ireland), we produce an ABM replicating typical movement patterns of residents in our study area, before introducing interventions that permit a more detailed exploration of the findings of Dixon et al., (2019) and Huck et al., (2019). In doing so, we will gain new understandings of how these findings might be deployed in order to promote positive inter-group relationships amongst segregated communities.

* jonathan.huck@manchester.ac.uk

2. Methods I: Input Datasets

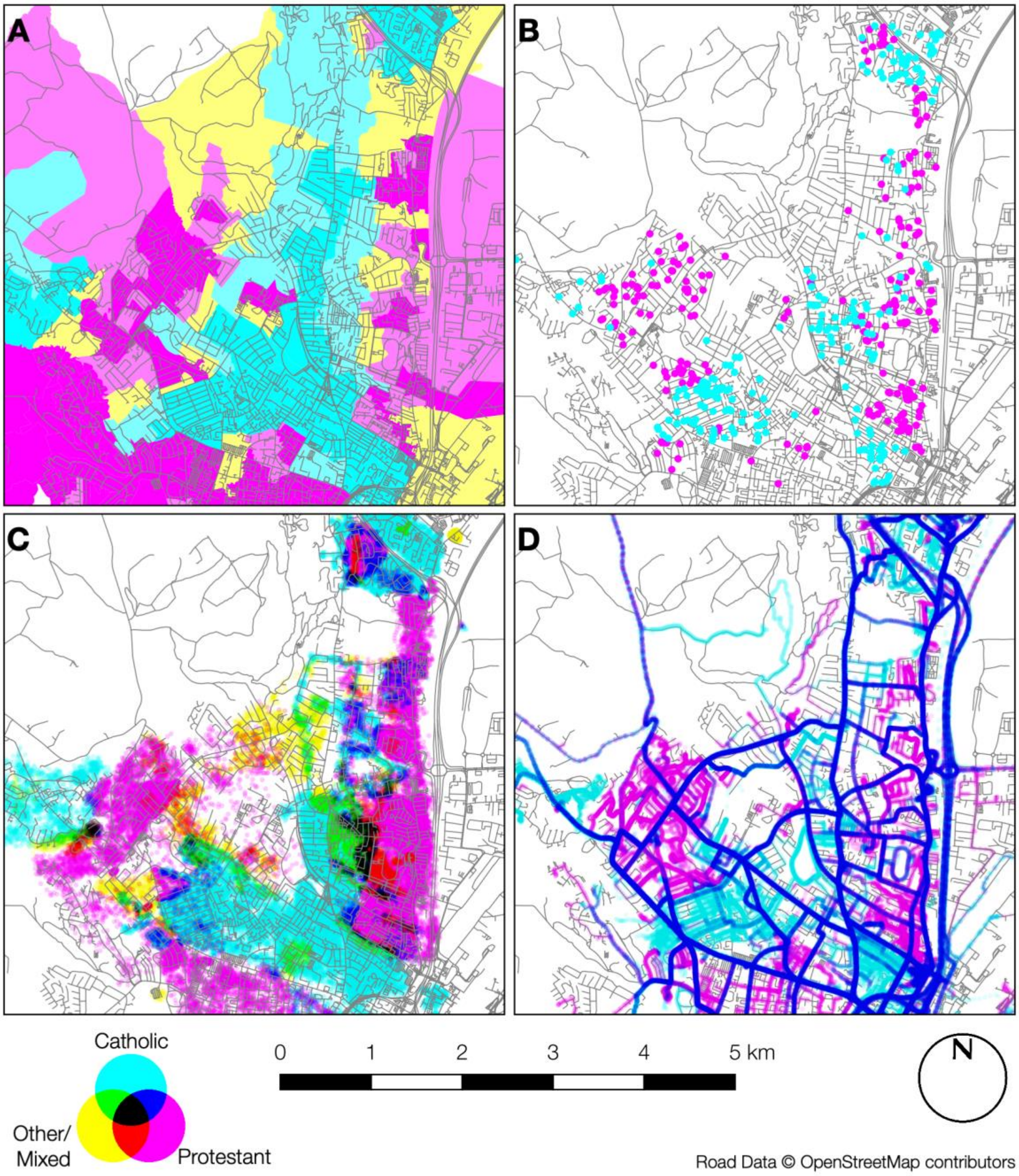

Figure 1: Input Datasets: (A) Census; (B) Survey; (C) PGIS; (D) GPS Traces

2.1. Census Data

Northern Ireland Small Area (SA) data of the 2011 census was obtained from NISRA†, including the percentage of Catholic, Protestant and 'Other' residents in each area (**Figure 1A**).

† https://www.nisra.gov.uk/support/geography/northern-ireland-small-areas

2.2. Survey Data

A paper-based questionnaire was administered to 488 participants (242 Catholic, 246 Protestant) in a door-to-door survey. The survey explored various aspects of identity, perceptions and experiences of segregation in Belfast (Dixon et al., 2019; Dixon et al., 2020). For the purposes of this study, only group (Catholic or Protestant) and the home location were used (**Figure 1B**).

2.3. PGIS Data

A Participatory GIS (PGIS) dataset was collected using the freely available Map-Me platform[‡] (Huck et al., 2014; 2019), which uses an airbrush-style interface that permits vaguely defined regions to be captured effectively, including spatial variations in strength of feeling. 33 participants (14 Catholic, 17 Protestant, 2 'Other') used the system to define places that they consider to be *Catholic*, *Protestant*, and *Mixed* (**Figure 1C**).

2.4. GPS Tracking Data

GPS traces were collected for a period of up to 14 days from 197 participants (93 Catholic, 92 Protestant, and 12 'Other') (Huck et al., 2019; Dixon et al., 2019). The participants collected data using a bespoke Android mobile application[§], which recorded GPS traces every 4 seconds, even if the app was closed or the device restarted. Data were cleaned as per Davies et al. (2017), and are illustrated in **Figure 1D**.

3. Methods II: Modelling

3.1. Modelling *Community Belonging*

The experience of segregation is incompatible with the official administrative boundaries with which communities are frequently represented by authorities and researchers (Huck et al., 2019; Davies et al. 2019). In order to better reflect community understandings of territory, we build upon the ideas posited by Huck et al. (2018) by producing evidence-based surfaces of *community belonging* (one each for Catholic and Protestant communities) to define territorial patterns across the study area. Formally, these two surfaces represent the probability that the next individual observed at a given location will be Catholic, or Protestant respectively; but here are used as a proxy for the extent to which a location might be considered to 'belong' to Catholic or Protestant communities.

These probabilities were calculated using Bayesian inference models (one for each 20m cell in each surface), each of which begins with a 'prior' belief taken from the census data (residential percentages). We then iteratively add evidence to the model, drawn from the survey data (reported group affiliation and home location), PGIS data (perceptions of 'Catholic' and 'Protestant' areas) and GPS tracking data (movements of Catholic and Protestant participants). Each set of 'evidence' was treated as a multinomial distribution of observations, with the parameter vector drawn from a Dirichlet distribution. Finally, we used a Markov Chain Monte Carlo (No U-Turn Sampler) approach to estimate the posterior distribution from 1000 sample draws. We took the mean and credible interval (CI; 95% of the values around the mean) from the resulting distribution and stored them into three bands of a GeoTiff (mean, lower CI and upper CI); giving both estimated values and uncertainties for each location in the surface. This analysis was implemented in Python[**], and the resulting surfaces are illustrated in **Figure 2**.

[‡] http://map-me.org
[§] https://github.com/jonnyhuck/bmp-pathways-app
[**] https://github.com/jonnyhuck/bmp-community-belonging

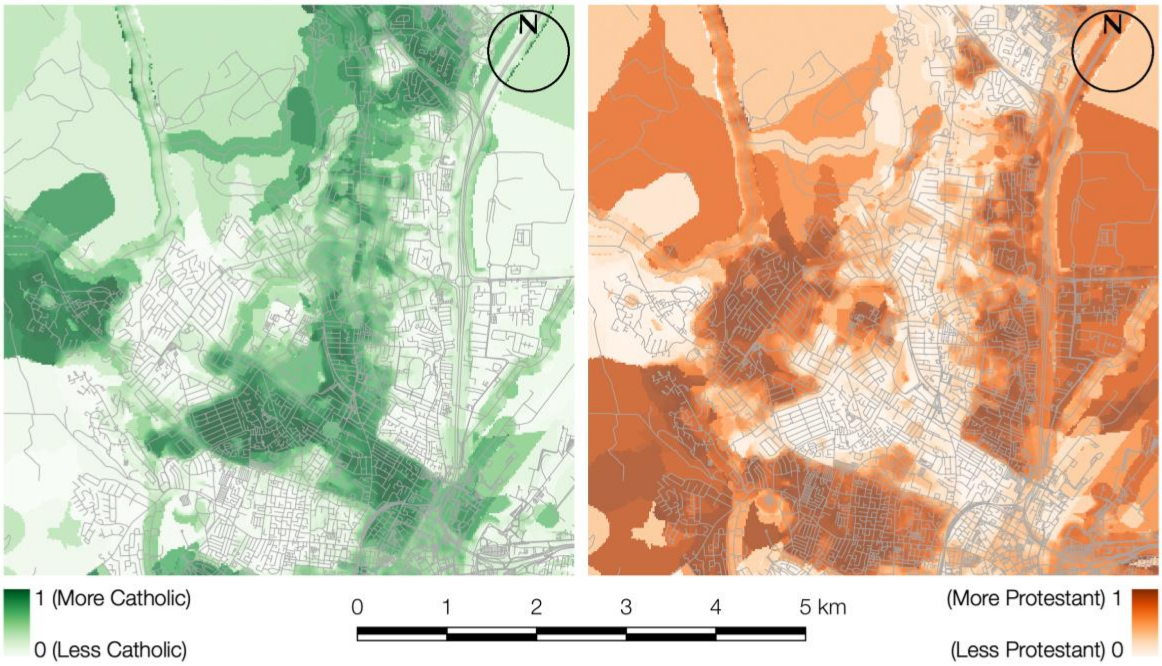

Figure 2: Probabilistic *community belonging* surfaces describing the degree to which a point in space 'belongs' to Catholic and/or Protestant groups.

3.2. Empirical Agent-Based Model

The *community belonging* surfaces (**3.1**) were then used to train an empirical ABM of individuals moving around the study area. Whereas many ABMs for the movement of individuals tend to draw upon theories and frameworks from the literature (e.g. Malleson et al., 2010), this one is based entirely upon behavioural evidence taken from the GPS tracking dataset (**2.4**). Each aspect of the agents' behaviour is drawn from probability distributions, which were parameterised through analysis of the GPS dataset that is described above.

The main parameters that control the agents' behaviour are a set of tolerances, which represent the maximum value of a cell that they are willing to enter in the above surfaces of *community belonging*. These tolerances are drawn for each agent from probability distributions based upon the participant behaviour in the GPS traces, compared with the *community belonging* surfaces. Tolerances are defined for:

- Residential Tolerance: where agents are willing to reside (home location)
- Movement Tolerance: where agents are willing to walk (by time of day)
- Destination Tolerance: which destinations agents are willing to travel to (by time of day)

Alongside these are other behavioural parameters including: number of journeys per day, time of journeys per day, destination type, journey distances, and transport mode (car/walk) – these are drawn from probability distributions constructed from the GPS tracking dataset.

Agents are 'seeded' into the model at their residential location, which is chosen through the iterative selection of random locations until one is both:

- below the agent's residential tolerance value on the 'community belonging' surface for the 'other' group
- within a 'residential area', defined using the dataset freely available from OpenStreetMap[††].

[††] https://www.openstreetmap.org

Each agent plans its journeys for each day based upon the above parameters, with destinations extracted from the GPS dataset and classified by type (e.g. shopping centre, school, supermarket, residential visit etc.) and destination tolerance. Routing is calculated using a modification of the A* algorithm, in which movement tolerances are enforced. In the event that a suitable route cannot be found to a selected destination (i.e. one that does not exceed the agent's tolerance), then it is replaced with another destination of the same class. An illustrative example of the ABM is given in **Figure 3**.

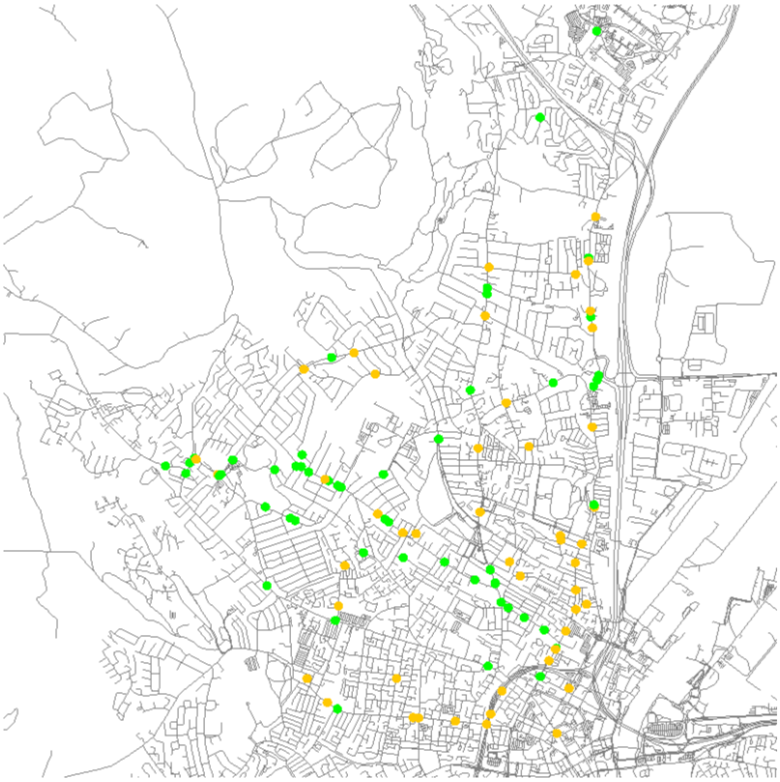

Figure 3: Screenshot of the Agent Based Model, running with an illustrative sample of 100 agents.

4. Model Validation and Results

As per the brief description in section **3.2**, agents move in space and time according to their unique, stochastic parameterisation. Visually, their movements reflect the patterns seen in the GPS dataset, as would be expected in an empirical behavioural model such as this. Nevertheless, a more formal validation of the movements will be explored.

Following satisfactory validation of the model, we will integrate a '*contact reinforcement*' mechanism (Dixon et al., 2019; 2020), in which agents that spend more of their time in the presence of the 'other' group will increase their tolerance values, and vice-versa. Using this, we will then undertake exploratory analysis into:

1. the extent to which attitudes would need to shift (both size of shift and number of individuals) in order to see significant changes in behaviour (*i.e. is there a tipping point?*)
2. the extent to which local interventions, such as the addition of new *non-places* (e.g. shopping malls) might impact upon contact (and therefore attitudes), and so contribute to such a shift in attitudes

These explorations will enable us to better understand the extent to which they would need to succeed in order to lead to large-scale behavioural change (a 'tipping point'); as well as predict the impact of physical (e.g. the construction of new facilities to promote contact) and social (e.g. educational) interventions.

5. Conclusion

The production and analysis of this model are still ongoing at the time of writing. The accompanying oral presentation would include the results of the exploratory analyses detailed in section **4**. We believe that these findings will provide new insights into the impact of social and environmental interventions upon positive contact, with clear policy implications for the reduction of segregation in Belfast and in other cities worldwide.

6. Acknowledgements

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This research relies upon the open source *MASON* (https://cs.gmu.edu/~eclab/projects/mason/) and *GeoMASON* (https://cs.gmu.edu/~eclab/projects/mason/extensions/geomason/) Java libraries; and the following free and open source Python libraries: *GeoPandas* (https://geopandas.org/), *Moving Pandas* (https://anitagraser.github.io/movingpandas/), *Rasterio* (https://rasterio.readthedocs.io), *Scipy* (https://www.scipy.org/), *Shapely* (https://shapely.readthedocs.io) and *PyMC3* (https://docs.pymc.io/). The agent-based model owes a lot to the '*burglarysim*' repository created by Nick Malleson (https://github.com/nickmalleson/burglarysim). OpenStreetMap data was retrieved from Geofabrik (http://download.geofabrik.de/europe/ireland-and-northern-ireland.html).

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8. Biographies

Jonny Huck is Senior Lecturer in Geographical Information Science at the University of Manchester, with research interests spanning PGIS, VGI and ABM; and application areas including Segregation, Global Health and Environmental Exposure.

Duncan Whyatt is Professor in GIS at Lancaster University with research interests in both the natural and social sciences.

John Dixon is Professor of Psychology at the Open University. His work focuses on the dynamics of intergroup contact, prejudice and segregation in historically divided societies.

Gemma Davies is the GIS Officer in the Lancaster Environment Centre, Lancaster University. Her research interests cover several areas of applied GIS, including food security; journey-time exposure to air pollution; and mobility.

Brendan Sturgeon is a Research Fellow in Anthropology at Queen's University, Belfast. His research interests include segregation and policing in post-conflict societies.

Bree Hocking is an independent writer and former Research Associate at the Open University. Her work focuses on spatial politics, identity, public art and the anthropology of tourism in post-industrial/post-conflict landscapes.

Neil Jarman is Head of Policy Research at Peace Direct, an NGO located in London. His research focuses on such issues as street violence, disputes over parades, management of public order, police reform, racist and homophobic violence and human rights in a number of countries including Northern Ireland, South Africa, USA, Israel/Palestine, Kosovo, and Nepal.

Dominic Bryan is Reader in Anthropology at Queen's University Belfast. His research interests include the politics of rituals and symbols in Northern Ireland and other divided societies.