

Spatial Patterns of Residential Segregation: A Generative Model

Flavia F. Feitosa¹, Joshua Reyes², Walter E. Zesk³

¹Center for Development Research (ZEF) - University of Bonn – Bonn, Germany

²Department of Computer Science – University of Massachusetts Boston - USA

³Rhode Island School of Design and Architecture - USA

flavia@uni-bonn.de, jreyes@cs.umb.edu, wzesk@wesleyan.edu

***Abstract.** Residential segregation emerges from the interaction of many individuals and displays markedly different global patterns depending on specific socioeconomic contexts. This paper presents a generative model of socioeconomic segregation that reproduces regular macro-patterns of the phenomenon through the specification of a minimal amount of parameters driving the agent's behaviour. The purpose of these experiments is to provide insights about the emergence of certain types of segregation patterns that have been identified in many modern cities and measure the relation between these distinct outputs and the degree of segregation they produce.*

1. Introduction

Residential segregation is a measure of social clumping in an urban environment. It has different meanings depending on the specific form and structure of the city, and its categories include income, class, race, and ethnic segregation. The effects of segregation in a city are mainly negative. In particular, socioeconomic segregation limits access of disenfranchised population groups to infrastructure and job opportunities, while reinforcing racial and social prejudices [Feitosa, *et al.* 2007; Sabatini, *et al.* 2001].

Residential segregation exhibits many of the characteristic hallmarks of complex adaptive systems, particularly emergence and non-linearity. Segregation is perceived as a large-scale urban phenomenon, but emerges from the interaction between individuals at a local level [Schelling 1978]. Positive feedbacks introduce a non-linearity into the system. As a result, small differences in socioeconomic and physical context and local behaviour can generate large, unexpected and sometimes counter-intuitive outcomes that cannot be understood as the simple sum of the constituent parts [Gilbert 2008]. Segregation occurs in most large modern cities, including the developed and the developing world. An examination of the patterns of segregation in various cities reveals the impact of specific socioeconomic environments. For example, most large cities in the United States have poor and non-white ghettos as a persistent feature of

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their central areas, whereas the wealthy and mostly white population prefers to live in suburbs [Massey and Denton 1993]. In Latin America, wealthy families concentrate in areas that expand from the historical centre into a single geographical direction, while the poorest population mostly settle in the roughly equipped peripheries [Sabatini, *et al.* 2001; Villaça 2001]. These two outcomes are generally recognized, but the structural aspects that cause these distinct patterns remain unclear. What part do individual needs and preferences play in the mechanics of segregation? How do socio-demographic factors, such as income inequality, impact the emergence of different spatial outcomes?

Generative models have been used to understand issues related to structural characteristics of complex social systems [Epstein 2007]. Most often, an agent-based computational model attempts to reproduce certain global regularities from minimally defined local interactions among individuals within the system. Such a model makes it possible to conduct experiments on a simplified population of agents in a spatial environment. Agents interact locally according to small set of rules, thereby generating global regularity from the bottom up. Simply, the motto of generative social approach is: 'If you didn't grow it, you didn't explain it' [Epstein 2007].

This paper presents a generative model of socioeconomic segregation that reproduces patterns much like those observed in real cities. The rules defining the experiment are few and simple. The purpose of this experiment is to create a stylized, abstract model that is able to provide insight into the mechanics of emergence and the variety of segregation patterns identified in modern cities. In addition, this work understands each pattern in terms of the degree of segregation produced. Our simulation enables the quantitative comparison of different patterns of segregation on defined segregation measures.

2. The Model Specification

Our model relies on the premise that socioeconomic segregation is the *outcome of a contest for the most convenient locations in the city*. In this model, only two attributes define how convenient a location is: the *quality* and *proximity* to the central business district (CBD). The environment consists of a two-dimensional 45 X 45 grid. Each cell within the grid corresponds to a dwelling unit. At the beginning of the run, each cell receives an equal quality rating. The initial price distribution falls off as the inverse of distance to the CBD.

Since the aim of our model is to 'grow' a city, the grid is initially populated with a minimum amount of agents. Each agent corresponds to a household, which is characterized by its location and income. Incomes are drawn according to a Pareto distribution, the skewness of which can be controlled by its exponent, known as Pareto index. The Pareto index regulates the level of income disparity in the city and can be chosen by the user: higher values lead to an unequal city, and vice-versa.

The city is gradually populated by households according to a growth rate. While looking for their residential location, the new inhabitants of the city attempt to maximize the utility U derived by a location over some subset of the presently unoccupied cells according to the Cobb-Douglas function:

$$U = \left(\frac{1}{D}\right)^{1-\alpha} Q^{1+\alpha},$$

where Q is the quality index of the cell, D is the distance to the CBD, and $\alpha \in [-1, 1]$ is the quality-priority index. The quality-priority index introduces a cultural bias to the model. Households will prioritize locations with high quality if α is near 1, and prioritize cell close to the city's center for values of α close to -1.

The individuals in this model exhibit bounded rational behavior. Because search is costly, every household evaluates a limited number of the total, possible locations to move to. Unlike other models of segregation, the households choose their new location without giving consideration their neighbours or their income explicitly. At each update, however, individuals compare utilities among others with similar level of income. Households with utilities that are much lower than those with similar income grow dissatisfied and may repeat the search process and move to another location.

As individuals choose their residential location, they change the environment. The model assumes that individuals with high income are able to advocate for more public goods in their neighbourhood, and therefore slightly increase property value (price) and introduce more services and facilities, such as improved school systems, police, or public parks (quality). On the other hand, individuals with low income lack similar resources, and so property value and public goods in those neighbourhoods decrease slightly.

The spatial arrangement of the population is constantly monitored through segregation indices. We selected segregation indices that are able to capture the segregation dimensions defined by Reardon and O'Sullivan [2004]: *spatial evenness/clustering* and *spatial exposure/isolation*. To measure each of these dimensions, we compute spatial indices of segregation proposed by Feitosa et al. [2007].

Spatial evenness/clustering refers to the balance of the distribution of population groups, and it is measured by the *generalized neighbourhood sorting index GNSI*. The *GNSI* evaluates how much of the income variance between different neighbourhoods contributes to the total income variance of the city. Generally, higher variance between neighbourhoods signifies higher levels of segregation along the dimension evenness/clustering. Spatial exposure/isolation refers to the likelihood for members from different groups to live side-by-side, and it is captured by the *spatial exposure index* $\tilde{P}_{(m,n)}$. The $\tilde{P}_{(m,n)}$ measures the average proportion of group n in the neighbourhoods of each member of group m . Since both these indices are global quantities, we also compute local indices of spatial isolation (\tilde{q}_m) that can be displayed as maps and facilitate the visual interpretation of the simulations [Feitosa, et al. 2007].

3. Growing Spatial Segregation Patterns

We ran our simulation several times for varying preferences and economic background. During these runs the quality-priority ranged over the values $\alpha = -1, -0.5, 0$, and $+0.5$ for each scenario captured by the Pareto inequality indices $\beta = 0.5, 1$, and 1.5 – cities with low, moderate, and extreme disparities in wealth. Each simulation ran until its population exceeded one thousand households.

Figure 1 presents the distribution of households for two runs in our experiment. The rightmost column depicts the physical distribution of households, colored by income, across the model's landscape. In this picture, squares with different tones of red, orange, and blue correspond to households with low, moderate, and high incomes respectively. In the middle of the rightmost columns, we have plotted the spatial isolation of the poor (\bar{q}_{POOR}) and of the wealthy ($\bar{q}_{WEALTHY}$). Dark cells signify areas where these groups are exceptionally isolated.

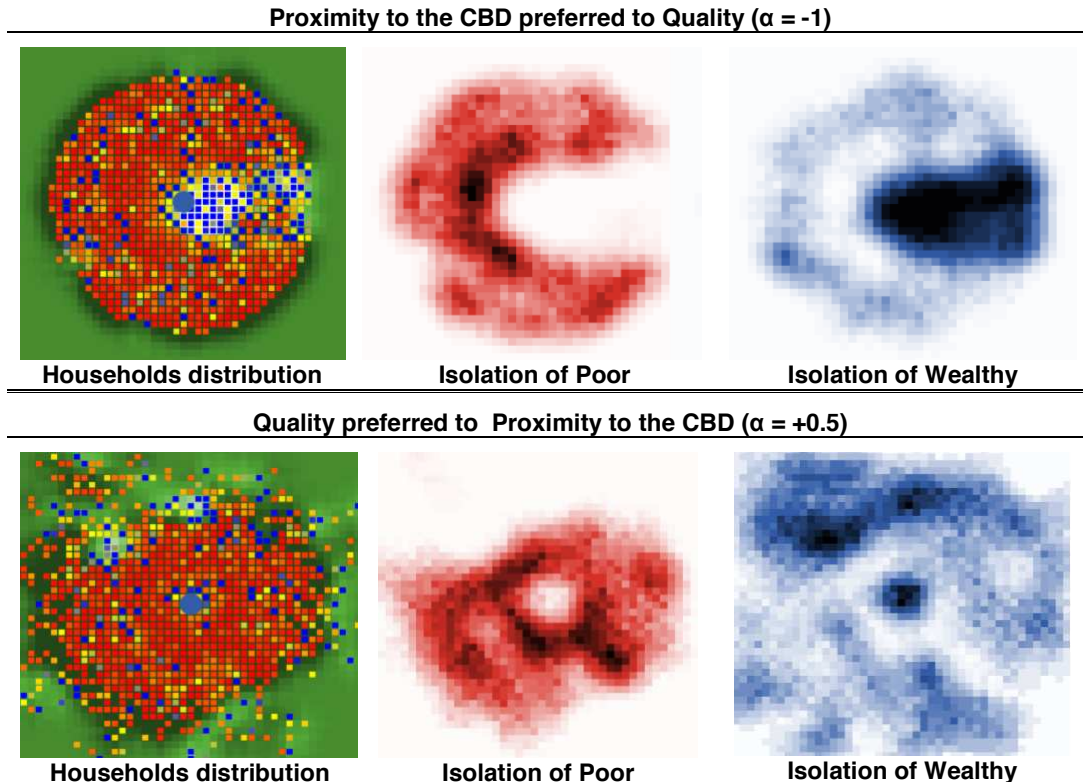


Figure 1. Simulation outcomes based on different values for the quality-index α .

We find that negative values of the quality priority index α , that is, the proximity to the CBD is preferred to quality, generate a very compact city. This output resembles a classical pattern of segregation known as Hoyt's sector model of segregation. According to Hoyt [1939], if a district is set up for high income residence, any new development in that district will expand from the outer edge and, therefore, the sector shape emerges. This sector pattern has been commonly observed in Latin American cities, where wealthy families concentrate in areas that expand from the center in a single direction. The top row in Figure 1 illustrates the case in this point.

On the other hand, positive values of α , that is, the quality is preferred to proximity to the CBD, generate a disperse city with wealthy suburbs. The bottom row in Figure 1 gives an example of this kind of city, which resembles a classical pattern of segregation known as Burgess's concentric model. For Burgess [1924], a city grows outward from a central point in a series of rings and there is a correlation between the distance from this central point and the wealth of residential areas. In North American

cities, where lower transportation costs decrease the importance of proximity to the CBD, we commonly experience this pattern of urban development.

Figure 2 presents plots of segregation indices measured for simulations conducted with four different values for the quality-index α . In order to obtain more robust results, we repeated these measurements using five different random-seeds and three different degrees of inequality (presented in different colors). The first graphic shows how the index GNSI, which measures the segregation dimension evenness/clustering, presents a positive correlation with the quality-priority index. The second graphic shows how the exposure of wealthy families to poor families decreases with the increase in the quality-priority index. Both results indicate that as soon as households attribute less value to proximity and more value to quality, the segregation level increased in both dimensions. Therefore, the ‘disperse city’ dominated by wealthy suburbs seem to be the segregation pattern that produces the highest levels of segregation. Regarding inequality, the graphics of Figure 2 reveal an unexpected result: while higher income inequality increases the segregation in the dimension evenness/clustering (GNSI), it increases the exposure amongst different income groups and therefore decreases the segregation in the dimension exposure/isolation.

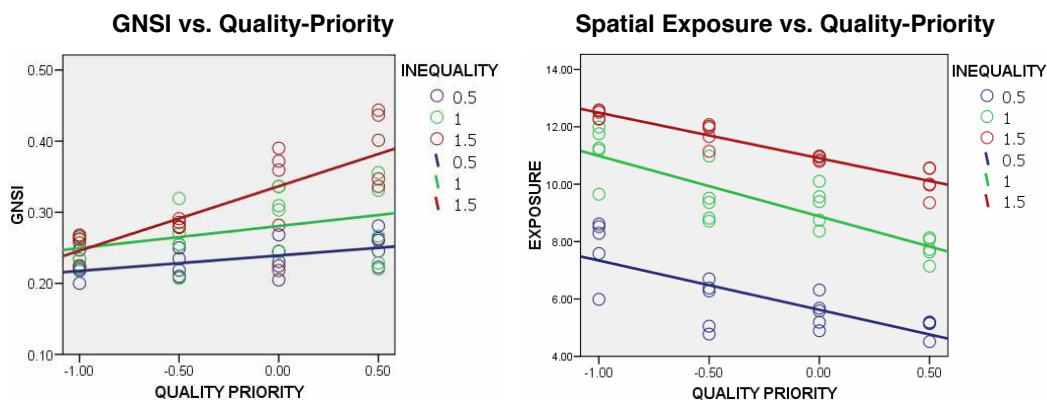


Figure 2. Segregation indices computed for simulation outcomes with different values for the quality-index α .

4. Concluding Remarks

This paper presents an agent-based model of segregation that generates patterns of segregation much like those identified in real cities. These patterns emerge despite the simplicity of the model. It is an example of how complexity can emerge from just a few parameters and suggests that these parameters are crucial to the underlying dynamics of segregation.

The model demonstrates how the variation of a single parameter, such as quality-priority was able to generate classical patterns of segregation. This is an indication of how cultural and economic environment influences segregation patterns. For instance, low transportation costs in North American cities minimize the importance of proximity to the center of the city and promoted the emergence of disperse cities with wealthy suburbs. It will be interesting to see the effect of the current energy crisis on segregation in these cities.

This work includes a quantitative comparison of segregation patterns through the application of global segregation indices. This is a particular advantage provided by generative models, since indices computed for real cities cannot be compared due to their susceptibility to the modifiable areal unit problem (MAUP). Our findings indicate that disperse cities produce higher degree of segregation in both dimensions, while unequal cities present higher degree of segregation in the dimension evenness/clustering, but not in the dimension exposure/isolation.

Segregation remains a remarkably common, persistent and difficult problem for cities of all types. Like many social phenomena, it grows out of simple interactions between individuals, but manifests as a complex resilient phenomenon at the scale of the city. Agent-based models provide a unique laboratory for experimentation and examination of this phenomenon, stripped down to its essential mechanics. We view this work as a simple kind of null model upon which urban planners and policy makers may introduce and isolate the effects of legislation, e.g., the social-mixed housing policies that have been recently instated in some North American cities.

5. References

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