Exploring the Role of Agent-Based Models in Residential Segregation

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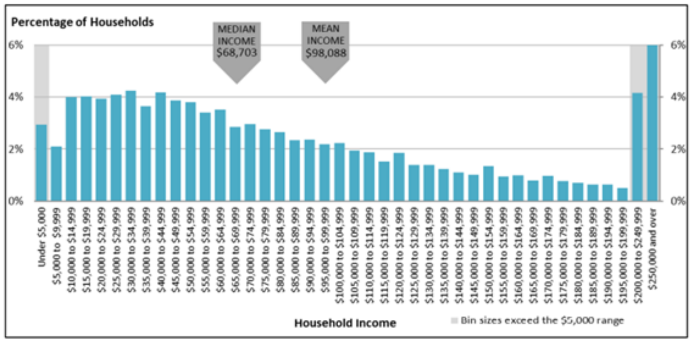
Word count: 721

Introduction

The Schelling model (Schelling 1971) demonstrates how individual preferences can transform an integrated city into a segregated one. It consists of agents on a square grid, where each cell can contain at most one agent. Agents are assigned one of two colors: blue or red. They remain in their current location if a sufficient share of their eight possible neighbors are of the same color; otherwise, they move to a random empty cell. The model iterates until no unhappy agents remain.

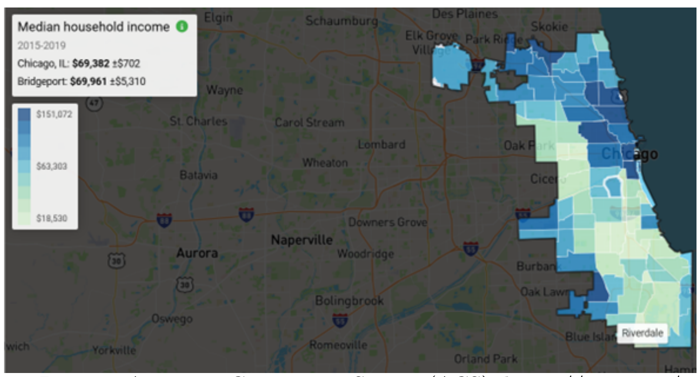
Model Modification and Motivation

This project adapts the original Schelling model to examine income-based residential segregation. Agents are assigned income levels drawn from a long right-tailed distribution to approximate the actual U.S. income distribution shown in Figure 1 (Congressional Research Service 2021). These agents are represented by a scale where yellow represents higher income agents and blue represents lower income. As in the original model, agents assess their satisfaction based on their neighborhood composition. Each agent has a satisfaction threshold, drawn from a uniform distribution between 0 and 1, representing the minimum required share of “similar” neighbors—defined as those whose incomes differ by no more than 10%. This similarity ratio is informed by data on median income and its variation across Chicago neighborhoods shown in Figure 2 (U.S. Census Bureau 2023). Agents incur a cost of one unit when moving and will only relocate if the utility gained from a higher share of similar neighbors exceeds this cost. However, agents do not have full visibility of all vacant locations; they consider only about ten randomly selected options. Additionally, agents who have previously moved become less tolerant of relocating again—their satisfaction threshold decreases, making them more likely to remain despite income dissimilarity. A detailed description of these changes for replication purposes can be found in the following section.



For the model, we are not considering the outliers at the bottom and top of the income distribution. Source: Congressional Research Service (2021).

Figure 1: Income distribution



Source: U.S. Census Bureau: American Community Survey (ACS), https://metop.io/insights/agqp

Figure 2: Income by neighborhood

Model Modifications for Replication

The following items describe each change in detail to facilitate replication. These modifications are also documented in the `README.md` file of the model. The `README.md` provides essential instructions for replicating the environment required to run the model, especially if this is your first time working with an ABM model using `mesa` and `solara`.

- **Change #1 – Agent income assignment using a right-skewed distribution:**
  Agents are assigned income levels by drawing from a log-normal distribution, which approximates the skewed nature of the U.S. income distribution. The values are then normalized to lie between 0 and 1.

- **Change #2 – Heterogeneous satisfaction thresholds:**
  Each agent is assigned a satisfaction threshold, randomly drawn from a uniform distribution between 0 and 1. This threshold determines the minimum proportion of similar neighbors required for the agent to be content.

- **Change #3 – Threshold adaptation mechanism:**

A new variable, `past_moves`, tracks the number of times an agent has relocated. Another variable, `adaptive`, can be set to `True` or `False` depending on whether adaptation is desired. If adaptation is enabled, an agent's threshold decreases by 0.01 after every 10 moves, reflecting increased tolerance due to moving fatigue.

- **Change #4 – Limited information in relocation decisions:**
  To simulate realistic search behavior, agents do not evaluate all available vacant cells. Instead, each agent randomly samples 10 available locations when considering a move, mimicking constrained search processes similar to browsing housing options online.

Research Question

Can segregation be modeled in an agent-based model (ABM) using different income classes? Can the introduction of moving costs and behavioral constraints mitigate segregation?

Tentative Hypotheses

1. Using a continuous income distribution instead of binary attributes will still produce segregation, but with more realistic interactions.
2. A uniformly distributed satisfaction threshold will slow equilibrium with respect to the 0.5 Schelling threshold, but it will not prevent segregation.
3. Since agents adapt their threshold, they will reach equilibrium relatively fast.
4. Introducing moving costs will increase the number of steps before segregation emerges, but will not prevent it.

Results

As hypothesized, segregation emerges even when using continuous variables such as income, rather than binary categories. Although factors like moving costs and behavioral rules—such as heterogeneous threshold mechanisms—can slow the segregation process, they do not eliminate it. In fact, threshold adaptation contributes to a relatively rapid convergence to a stable equilibrium, typically within 57 steps (Figure 3).

Segregation patterns begin to form within the first few steps of the simulation (Figure 4). Agents at the extremes of the income distribution—those in the tails—tend to move more frequently and take longer to reach a stable state, as their satisfaction depends on more specific neighborhood compositions. However, these agents also display signs of "moving fatigue": over time, their tolerance increases, allowing them to settle in neighborhoods that may not perfectly match their preferences but are "good enough" to stay.

Interestingly, these behavioral rules mitigate the intensity of segregation (Figure 3), leading to more mixed rather than sharply divided patterns. Disabling the adaptive mechanism produces the

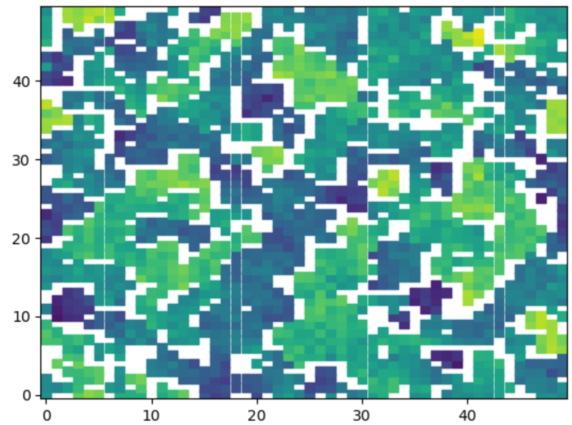


Figure 3: Grid output: Adaptive behavior

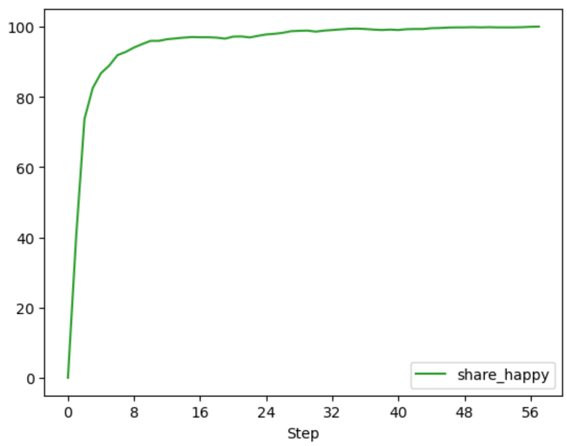


Figure 4: Share of happy agents

results shown in Figure 5. As shown, the non-adaptive scenario results in slightly more pronounced and concentrated segregation (particularly visible in the yellow -high income- agents). Moreover, agents with high satisfaction thresholds or income levels at the extremes of the distribution struggle to find equilibrium. These agents may continue moving for 701 steps before settling.

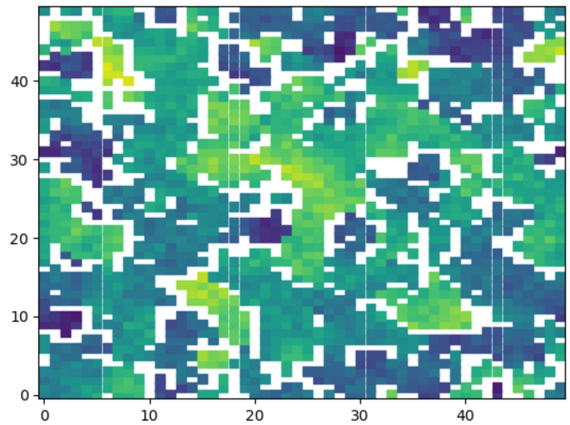


Figure 5: Grid output: Non-Adaptive behavior

Discussion and Implications

These modifications offer a more realistic lens through which to understand segregation. While agents still operate based on neighbor preferences, the addition of income heterogeneity, tolerance variability, and mobility constraints brings the model closer to real-world residential dynamics. This also reflects patterns observed in cities like Chicago, where income distributions vary significantly by neighborhood. For instance, wealthier areas exhibit right-skewed income distributions, while many southern neighborhoods display lower income levels. Similar trends appear in other urban areas.

By exploring income-based segregation, this model broadens the scope of the Schelling framework. In future work, this model could be extended by introducing an additional agent: a landlord or housing agency. Such actors might introduce biases in housing availability or pricing, which could further influence segregation outcomes.

References

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