Eidgenössische Technische Hochschule Zürich
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Complex Social Systems:
Modelling Agents,
Learning and Games

Semester Project

The Schelling Model

Integrating Price Dynamics and Points of Interest

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Abstract

This report introduces an agent-based model simulating an urban environment, where agents make residential decisions based on various attributes. Agents, defined by types, wealth, and interests, interact in a grid-based landscape with differing cell types and prices influenced by population density. The model incorporates satisfaction metrics, factoring in similarity, desirability, and affordability, dictating agent relocation.

Simulation outcomes demonstrate diverse agent segregation patterns influenced by satisfaction thresholds and strategy weights. Strategies including randomness, distance, and price dynamics yield distinct segregation behaviors, showcasing varied levels of stability and convergence. Integrating multiple strategies unveils more realistic urban forms, emphasizing the impact of points-of-interest and price dynamics on segregation dynamics.

The distance model reveals agglomeration around points-of-interest, reducing segregation, while the price model depicts higher segregation due to affordability constraints. The combined model presents a realistic urban layout with a core center and peripheral areas, reflecting varied agent preferences and economic disparities.

This model contributes insights into urban dynamics, shedding light on how points-of-interest and economic factors shape segregation patterns in simulated urban landscapes.

1 Introduction

Globalization has brought substantial changes in urban structures, increasing the competition for social and economic capital and reshaping the demographic composition of cities due to new demands for labor force [1]; this new dynamics of intercity mobility, in combination with increasing market competition, has generated the displacement of low-income individuals, amplifying social segregation [2]. This segregation significantly influences the social structure, economic opportunities, and the overall distribution of resources within communities [3, 4, 5].

The first studies of social segregation were conducted by the Chicago School of Sociology, which proposed three stages of immigration residential choice and the integration of these communities into urban life. The first stage was the *inner-city ghetto*, in which immigrant communities tend to live in impoverished areas, spatially separated from other groups, the *upward mobility*, in which these groups start integrating into the urban life as part of the workforce, until the final phase which is *dispersal*, in which this group was fully integrated into the city [6]. However, it was not until the work of [7] that the segregation dynamics were modeled, which created the base for understanding how local interactions among agents can lead to global patterns of spatial segregation. This model is considered one of the first applications of agent-based models in social sciences and shows the dynamics of self-organization in the housing market and how mild preferences for neighbors of similar characteristics can generate entirely segregated neighborhoods.

In order to understand segregation, it is essential to analyze the underlying dynamics that generate those patterns and to measure the impact that individual decisions have on the macro behaviors of the system, generating valuable information for policymakers and urban planners seeking to create more inclusive and integrated cities [8]. For this reason, this manuscript proposes an improvement in the Schelling model, integrating price dynamics and points of interest into the original Schelling model. We can generate more realistic behaviors that consider the importance of neighborhood preferences, the costs of land, and the benefits associated with living in an urban area.

The manuscript continues as follows: Section 2 describes related work and other improvements to the Schelling mode, section 3 describes the proposed model, section 4 shows the final results, and section 5 presents the discussion and relevance of the model proposed.

2 Related Work

The first model of dynamic segregation was proposed by [9]. The model consists of a chess-like space where agents (blacks and whites) are randomly assigned to the available squares. The agents change positions following one rule: if the proportion of similar neighbors of the agent is lower than a pre-defined tolerance threshold, the agent moves to another position. The dynamics of the agent's decisions can generate patterns of segregation, integration, or segregation-integration mixes depending on the tolerance thresholds [10]. The literature has further advanced the original model and its implications, [11] has generated heterogeneous group size, showing that the big group generates a core segregated neighborhood. In contrast, the smaller group will spread in the periphery. Other improvements have been generating random agents that move independent of the number of similar neighbors and their final situation, in combination with varying the number of empty locations; the lower the number of empty locations, the harder it is for agents to find a suitable location, leading to sub-optimal results. Conversely, the random agents generate better individual-level solutions as it can free space for unsatisfied agents to occupy [12]. Heterogeneous preferences reduce the levels of segregation [13]. [14] introduces utility functions into the model, to estimate willingness-to-pay for being with similar agents. Finally, [15] implemented a simultaneous decision game in which all agents choose where to move simultaneously, resulting in higher levels of segregation, as agents in good positions attract all dissatisfied agents at once. The Schelling model has shown that even small preferences for neighbor similarity can lead to completely segregated patterns, making it difficult to separate micromotives from macrobehaviors [16]. The model has been improved with new rules and interactions that change the final segregation patterns, which helps generate more realistic models. Therefore, further development on the Schelling model is needed to generate more realistic behaviors and how those affect segregation.

3 Model Description

This agent-based model operates in a discrete spatial grid representing a fictional urban environment. Each cell represents a location where an agent lives or can move to.
Each agent is characterized by a set of attributes that influence its decision-making process:

- **Agent Type:** Reflects diverse groups within the simulated community, akin to the heterogeneity observed in real-world societies.
- **Wealth:** Represents an agent's income available for housing.
- **Interests:** Signifies specific preferences for amenities or neighborhood traits, influencing satisfaction levels and residential decisions.
- **Satisfaction Threshold:** It the minimum proportion of similar neighbors an agent wants in their neighborhood.

The spatial landscape comprises a grid of cells characterized by:

- **Type:** Different cell types symbolize various urban amenities.
- **Price:** Is an indicator of the cost or value associated with residing in specific locations, akin to real-world economic factors influencing housing choices.

The pricing of the cells is dynamic, if the surrounding of the cell is highly populated, the price of the cell increases, whereas if the density of the population is low, the price of the cell decreases.

At the begining of each iteration, each agent scan their personal situation in terms of neighbours and location price. An agent becomes dissatisfied in a location if at least one of the two following conditions holds:

1. The proportion of neighbours of different type to the agent is higher than the agent's satisfaction threshold.
2. The location is not affordable for the agent, this happens when many individuals move near that cell, increasing its price.

The satisfaction score is calculated as follows:

$$\text{Satisfaction} = \frac{\text{Similarity} + \text{Desirability}}{2} \tag{1}$$

Where:

$$\text{Similarity} = \frac{\#\ \text{Similar Neighbors}}{\#\ \text{Neighbors}}, \tag{2}$$

and

$$\text{Desirability} = w_{\text{price}} \cdot [\text{Wealth} = \text{Price}] + w_{\text{distance}} \cdot \frac{1}{\text{Distance}} + \epsilon, \tag{3}$$

Here, *Similar Neighbors* refers to neighbors of the same type as the agent that are located in direct contact with the agent, and *Distance* denotes the distance to a point of interest. w_{price} and $w_{distance}$ are weighted factors representing the importance of price and distance for the agent, respectively, while ϵ is independent and uniformly distributed random noise.

As one can read from equation 2, the similarity score for an agent at a given location is higher if a more significant proportion of neighbors is of the same type as the agent.
The Desirability score (3) aims to match an agent's wealth with the price, ensuring a higher chance of being surrounded by similar-wealth agents, reflecting the preference of agents to live closer to preferred amenities. The significance of each factor depends on the agent and is represented by the weights w_{price} and $w_{distance}$.

If an agent's satisfaction falls below its threshold during an iteration, it moves to a more desirable location. To select the target cell, the dissatisfied agent evaluates available empty cells and chooses the one with the highest desirability score. This selection can be expressed as:

$$\text{argmax}_c \left(\text{Desirability}(c) \mid c \text{ is an empty cell}\right) \tag{4}$$

The model operates through iterations, each representing a step in the simulation timeline. Agents adapt decisions based on evolving neighborhood attributes and individual characteristics, resulting in dynamic spatial patterns reflective of real-world scenarios.

4 Simulation and results

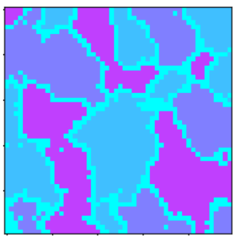

Figure 1: Random strategy

Figure 2: Distance strategy

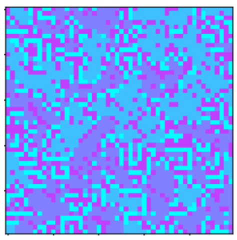

Figure 3: Price strategy

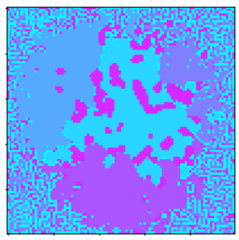

Figure 4: Combined model

We have implemented four different models, with different strategies to look for new neighbours. In the first model, *Random strategy*, when an agent is dissatisfied with the similarity of their neighborhood, it moves to a random empty location. This model does not consider prices or amenities, and it is the most similar to the original model proposed by Schelling. The second model considers amenities. When an agent moves, it looks for the closest available spot to the amenity of their preference. Model 3 considers price dynamics, and finally model 4 is a combination of models 1, 2 and 3.

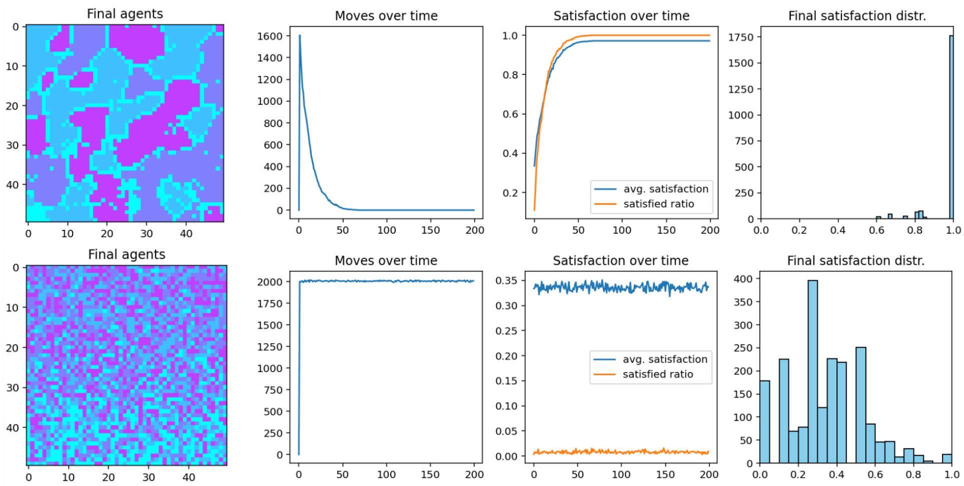

Figure 5: Stable vs unstable models

Depending on the choice of input parameters, the model either converges on a stable state where all agents are satisfied, or keeps changing indefinitely. With the introduction of random noise in cell desirability, the model may not reach a convergence.

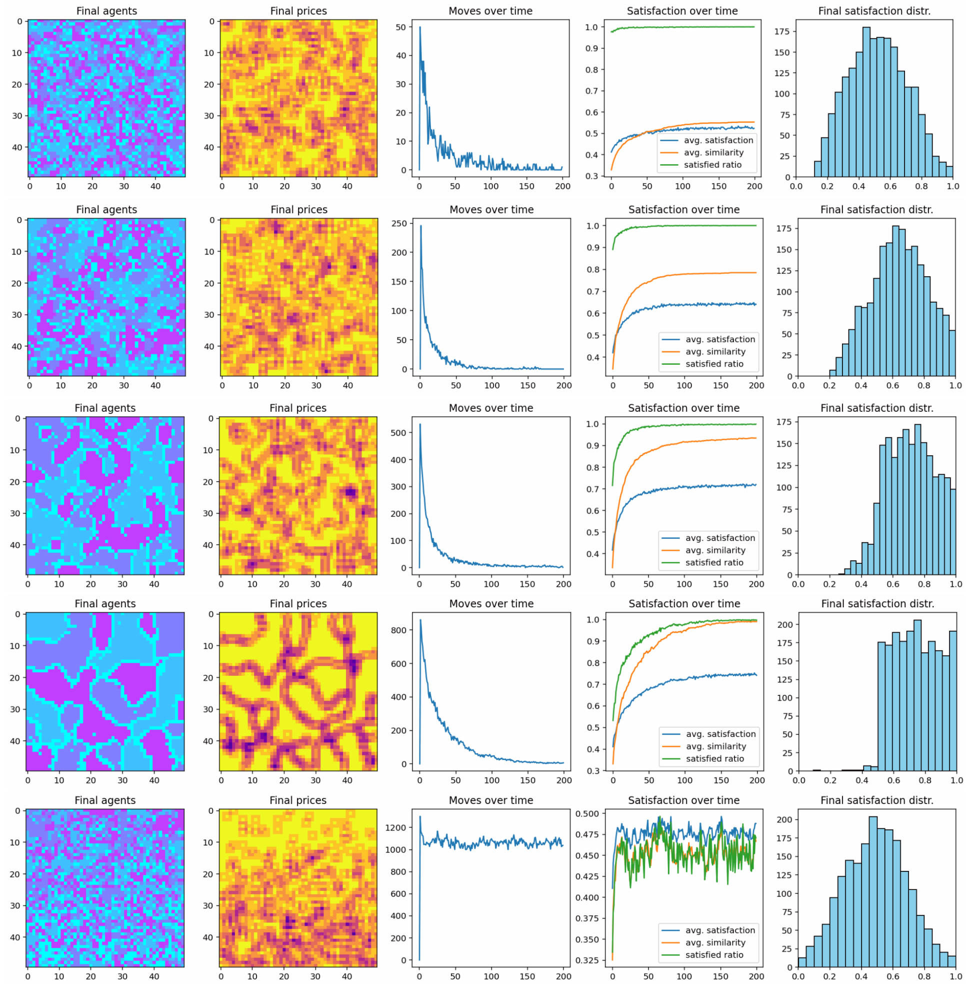

Figure 6: Random strategy with thresholds [0.1, 0.2, 0.3, 0.4, 0.5]

Varying the agent satisfaction threshold parameter controls how strongly agents segregate and impacts whether or not the simulation converges. A low threshold value results in a model that converges quickly but does not show significant segregation, while high threshold values cause agents to never settle down and move indefinitely. These ranges vary depending on strategy weights and other parameters. Using an emptiness factor of 0.2, 3 agent types with equal ratios, and a grid size of 50 over 200 iterations, the following approximate values could be determined.

Agent threshold values	Unsegregated	Fast stabilization	Unstable
Base model	< 0.30	0.60	> 0.67
Random strategy	< 0.20	0.40	> 0.45
Distance strategy	< 0.10	0.30	> 0.40
Price strategy	< 0.10	0.25	> 0.35
Combined model	< 0.15	0.30	> 0.40

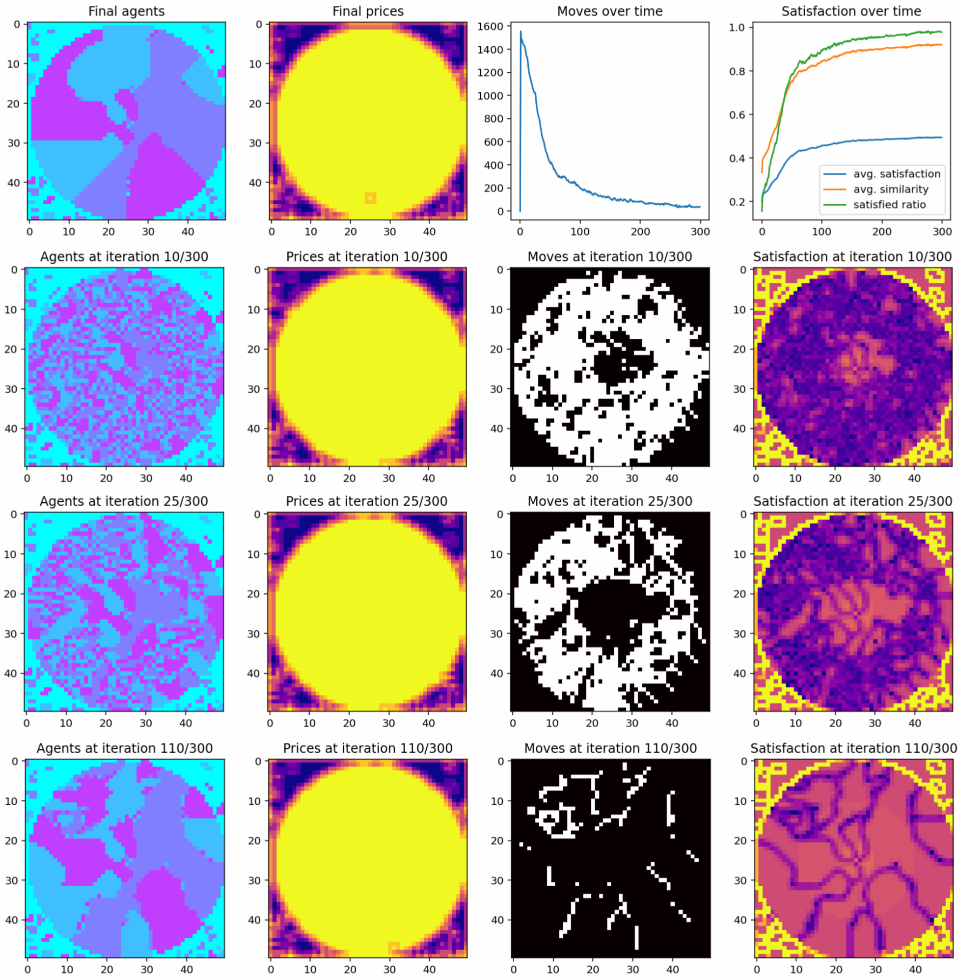

Figure 7: Distance strategy

Using the distance strategy, agents instantly form a perfect circle around the point of interest at (25, 25). They then slowly sort themselves into segregated groups to maximize their neighborhood similarity and overall satisfaction.

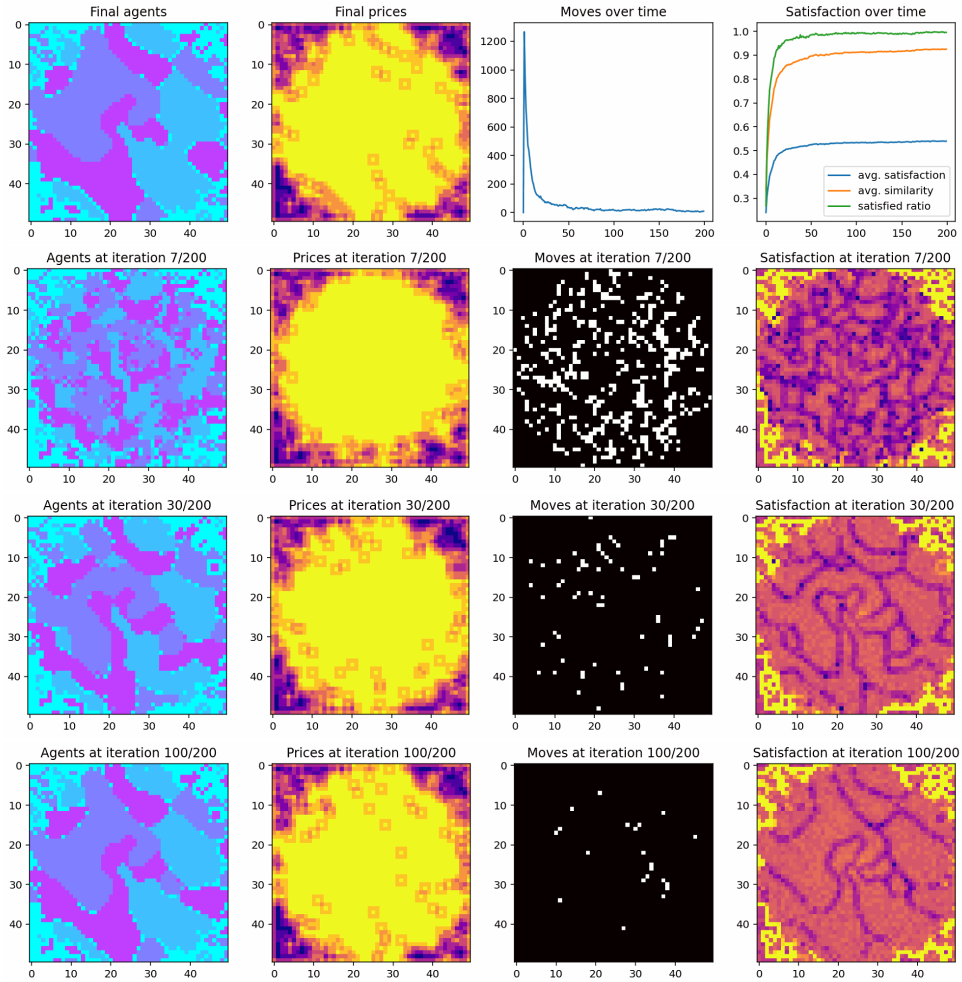

Figure 8: Distance and random strategy with weights (0.8, 0.2)

By introducing random noise via the inclusion of the random strategy with a weight of 20%, agent behavior becomes more realistic, the population density increases more gradually towards the center, and the model converges much quicker.

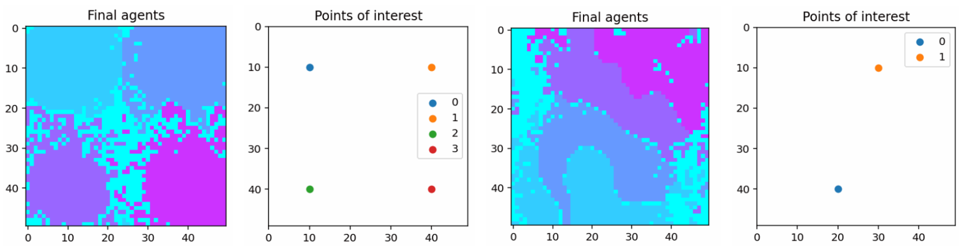

Figure 9: Multiple points of interest and different agent interests

Agent types with different interests will group according to proximity to their preferred points of interest. The second figure uses agent interests [(1.0, 0.0),(0.8, 0.2),(0.2, 0.8),(0.0, 1.0)] and results in a corresponding gradient.

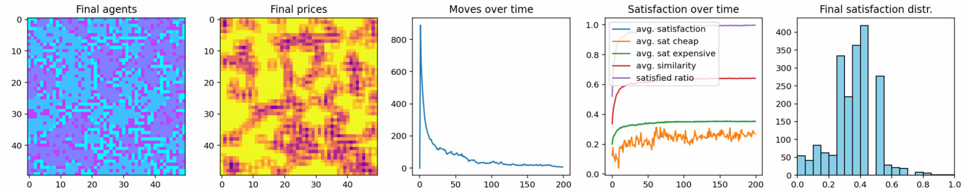

Figure 10: Price strategy

The price strategy results in high income agents being more satisfied and therefore moving and segregating much less than low income agents. (low → high: cyan → purple)

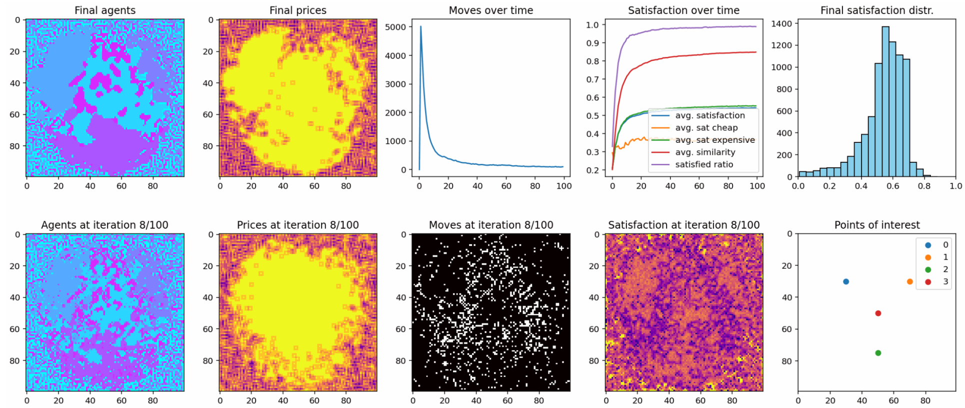

Figure 11: Combined model

The final combined model uses strategy weights (0.4, 0.4, 0.2), a satisfaction threshold of 0.3, an emptiness factor of 0.2, 5 agent types with equal ratios and a grid size of 100 over 100 iterations. There are 4 points of interest with all agents having interest 1.0 in the center point, and agents 2-4 additionally having an interest of 0.3 in each outer point respectively. The agents have wealth [16, 18, 19, 22, 24].

5 Discussion

The model presented in this manuscript improves the Schelling model by integrating the impact of two characteristics of cities and their effect on segregation: points of interest and price dynamics. Both characteristics change segregation dynamics differently, adding realism and showing new dynamics generated by these characteristics.

The distance model integrates points of interest representing locations that benefit people, such as parks or plazas, culinary districts, and others. The results show that agents tend to agglomerate around those POI, lowering the average level of segregation as they are willing to sacrifice part of their neighbor similarity in order to be close to those points; these results converse with [17], who shows that urban venues can reduce segregation as individuals tend to prefer to live closer to them. A second interesting result is the impact on urban form or agglomeration dynamics; the POIs generate a core urban area where most agents live with a small group of agents living in the periphery as their initial state is satisfactory.

The price model represents the price dynamics generated by the housing market, with higher prices in more dense locations. The changing prices do not generate a clear city-core as the distance model. However, it generates lower levels of segregation as low-income individuals cannot find a location of preference due to the high prices. In contrast, wealthier individuals can find a satisfactory location quickly and do not have to move. This generates an unstable model, as low-income individuals do not find a satisfactory cell, moving indefinitely.

Finally, the model that combines both POIs and price dynamics shows a more realistic urban form as a core center is generated with most agents living around it in small communities of similar agents and a peripheral low-density area; this second area shows lower levels of segregation as individuals try to spend most of their income in the locations while not having many similar neighbors. This model also shows how the dynamics of gentrification work, as low-income individuals can randomly start living close to their preferred Point of Interest. However, due to the increase in prices generated by the arrival of new neighbors, these agents are forced to move further places.

The results of our model are relevant to the literature as they improve the Schelling model by adding price dynamics and points of interest, which makes the model closer to how urban agglomerations work and helps understand how different policies could affect urban segregation.

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