Dynamic Models of Urban Segregation

Complete List of Authors:
Ultan Byrne
Lecturer,
John H. Daniels Faculty of Architecture, Landscape, and Design.
University of Toronto

Daniel Silver
Associate Professor,
Dept of Sociology
University of Toronto Scarborough

Patrick Adler
Research Associate,
Rotman School of Management
University of Toronto

Abstract: This paper proposes a computer simulation framework for investigating the role of built form – specifically physical venues -- in the dynamics of neighborhood integration and segregation. Looking to Schelling’s classic work (1971) and the subsequent literature, we note, however, that with few exceptions ‘form’ in these models is reduced to an agent’s capacity to ‘see’ nearby grid-cells of the simulation world: an agent’s neighbourhood is its Moore neighbourhood. In this research, we argue that an analytically meaningful simulation of neighbourhood formation – or more specifically of integration and segregation dynamics – must acknowledge the role of built form. To do so, we introduce physical venues into the classic Schelling model in order to reconsider the simulation’s dynamics as influenced by both the spaces where agents live and the spaces of their activities. Our analysis proceeds through a series of four case studies of increasing sophistication, considering the impact of different spatial configurations as well as different kinds of venue. We articulate a simple but powerful generative model of urban social formations that also may offer insight into the conditions under which sedimented patterns of segregation may become unsettled.

INTRODUCTION
What is the role of built form in constituting distinctive neighbourhoods? While a common idiom such as “the wrong side of the tracks” suggests a delineating role of certain infrastructures, at the same time, churches, markets, and other architectural features can act as loci of communities. Indeed, the impact of transportation networks, the distribution of building types, and real estate markets can generate spatially distinct communities dispersed throughout a city.

In this paper, we propose a computer simulation framework for investigating the role of built form – specifically physical venues -- in the dynamics of neighborhood integration and segregation. We extend and build upon three literatures. A first is primarily ethnographic, and highlights venues (such as laboratories, churches, conference centers) as foci of social interaction, in which groups repeatedly meet (Menchick 2017). Different venues prescribe different forms of activities, which in turn provide structure and meaning to groups who utilize them, as well as targets for conflict and contestation. A second literature is more focused specifically on urban segregation, and often highlights how the physical layout of cities shapes residential and mobility patterns (Roberto 2017). This literature suggests that the number and distribution of venues structures the formation of urban communities.

A third is most central to our work, and stems from Thomas Schelling’s classic paper, “Dynamic Models of Segregation” (Schelling 1971). This paper laid the ground for a literature on agent-based models (ABMs) of segregation, and is a key reference point for ABMs more generally (Cederman 2005: 874). This literature has been very influential in deriving macro-patterns of segregation from simple rules of individual behavior, and the results have often been taken to offer insight into existing urban settlement
formations (for example, Benenson, Omer, and Hatna 2002). We note, however, that with few exceptions ‘form’ in these models is reduced to an agent’s capacity to ‘see’ nearby grid-cells of the simulation world: an agent’s neighbourhood is its Moore neighbourhood. In this research, we argue that an analytically meaningful simulation of neighbourhood formation – or more specifically of integration and segregation dynamics – must acknowledge the role of built form. To do so, we introduce physical venues into the classic Schelling model in order to reconsider the simulation’s dynamics as influenced by both the spaces where agents live and the spaces of their activities. Accordingly, our analysis contributes to multiple literatures while articulating a simple but powerful generative model of urban social formations that also may offer insight into the conditions under which sedimented patterns of segregation may become unsettled.

Our analysis proceeds through a series of four case studies of increasing sophistication. Throughout we observe novel combinations of integration and segregation, brought about by the interaction between agents and venues. In our first study (1), we investigate different spatial configurations of venues from simple geometric distributions to a core and periphery model. Findings highlight the more realistic settlement patterns emerging from the interplay of a planned configuration of venues and the self-organizing behaviour of agents. In our second study (2), we consider variations in a venue’s exclusivity – the extent to which venues of a given group are open to admitting members of other groups. We discuss the parameters under which a range of outcomes result, from integration made possible by adjacent and exclusive venues, to ‘co-opting’ that can be caused by highly inclusive venues. In the third study (3), we build on prior experiments in the literature that have examined unequal population sizes, and demonstrate how majority/minority dynamics are affected by the presence of physical venues. Finally (4), after noting the high stability of segregated outcomes in Schelling-style simulations, we apply our venue model across a range of parameters in order to evaluate conditions under which settled, segregated neighbourhood patterns become disrupted.

In addition to their particular substantive points, a persistent interest of these studies is whether – and under what parameter ranges – access to group-specific venues allows individual agents to be comfortable remaining in a more diverse neighbourhood vs. these same venues becoming attractors that reinforce Schelling dynamics of segregation. In the process of introducing the case studies, we also describe and deploy a series of methodological innovations. For example, we begin each study with a visualization of the variety of simulation outcomes across value ranges of two input parameters (for example “intolerance threshold” vs. “maximum travel distance”). These representations, which we refer to throughout as parameter spaces of the simulations, organize the discussions of our findings and allow us to emphasize significant steps or thresholds, where small changes in the input parameters yield large changes in the results (Schelling’s classic example of which is the intolerance threshold around 1/3\(^6\)). Where necessary, we also introduce specific techniques of visualization and analysis to effectively characterize the movements of agents and the resulting patterns of clustering in relation to the built form of the simulations. For example, in the fourth study, we deploy a genetic algorithm to perform a non-linear search for significant combinations of input parameters and venue locations. The results thus offer a range of methodological, theoretical, and substantive insights.

**REVIEW OF LITERATURE**

As the title suggests, our research engages directly with Schelling’s “Dynamic Models of Segregation” and its Agent-Based Model (Schelling 1971). In this section, we summarize the model before briefly surveying the intervening research on modeling urban segregation with which our own work either shares features or differs in instructive ways. Next, we briefly discuss related literatures on built form, venues, neighbourhood formation and urban segregation to further motivate and inform our analysis. Finally, these references will return us to reflect on an enduring question for simulation-based methodologies and consider the positions taken by Schelling, more recent contributors, and ourselves.
Schelling (1971) is the locus classicus for a fundamental social scientific insight: individuals’ micromotives can generate collective macrobehaviors that need not reflect (in a straightforward way) their intentions. In this case, individuals motivated by a relatively high degree of tolerance produce highly segregated “neighborhoods,” even if this is not what they intend. To demonstrate this, Schelling describes an experiment involving a random distribution of simulated individuals from two distinct groups (which for our sake will be represented as Red and Blue) in a two-dimensional grid of cells (see figure 1). Schelling imbues these agents with simple threshold based behaviour: if the ratio of like-neighbours (where likeness refers to shared group membership) to total neighbours is below some value, the agent will attempt to relocate to an empty cell where this measure is satisfied. Schelling would have us think of this threshold-value as representing the relative tolerance or intolerance of the agent towards members of the other group. The neighbourhood within which this tolerance is measured is defined as the surrounding cells up to some maximum distance (whether as a Moore or Von Neumann measure) from the agent’s own location. If an agent is compelled to move based on their current neighbourhood, they will consider moving to available grid cells (closest first for Schelling, random order in our studies1) until they find an appropriate new location. If none of the available cells are satisfactory, the agent will remain at their current location, looking for an appropriate destination each turn or until the makeup of their neighbourhood changes. The movement of each agent can prompt moves by other agents in the neighbourhood of its previous location, its new location, or both. Schelling’s discovery is that based only on this local and simple decision-making procedure, larger scale patterns of behaviour appear. Crucially, he points out that there are particular tolerance values for which these macro patterns are not intuitively linked to the micro motives of the agents. For example, after a series of moves, a relatively tolerant initial population (comfortable with as little as one-third of their neighbours being of the same group) will resolve itself into segregated patterns at the overall scale of the simulation world (see Video 1). Equally crucially, once these segregated patterns emerge, they are very difficult to unsettle, at least within the rules governing the traditional Schelling-style simulation environment.

Subsequent research has tended either to systematically investigate simulation outcomes by varying the model’s input values, or to expand on Schelling’s work by introducing altogether new parameters. In the former category, Fossett and Dietrich’s thorough testing of the robustness of Schelling-style outcomes to a variety of inputs is an important resource in the design of our own experiments (2009). Laurie and Jaggi’s study of the agents’ concept of neighbourhood distance or “vision” (2003) as well as Fossett and Waren’s response (2005), are also relevant to our research, in which different measures of distance play an important role. In the latter category, a number of researchers have introduced new parameters or features

1 While Schelling himself describes using a “closest move” rather than “random move” (Schelling 1971: 155), we follow the subsequent literature on this point. Note additionally that this random movement means that agents do not necessarily seek out the ‘ideal’ or maximally satisfying location, their behavior is satisficing instead.
that attempt to increase the realism of the Schelling model. For example, some have followed the logic of the bounded-neighbourhoods that Schelling also describes in his 1971 paper. They implement the boundaries in various ways – from “block” communities (Sander et al 2000) to the use of the city of Buffalo’s census boundaries as neighbourhood divisions (Yin 2000). While bounded implementations of neighbourhoods can be seen as integrating urban form into the simulation world (insofar as they might represent city blocks or districts), they do so only by foreclosing an important part of our research. Since we hope to study the influence of urban form on neighbourhood formation, to define the neighbourhood in terms of urban form is to beg the question. Instead, we are seeking a generative explanation of neighbourhoods that can accommodate the influences of both individual dynamics and aspects of urban form.

A more direct precedent is Wasserman and Yohe’s introduction of “public goods” in their variation on the classic simulation (2001). These spatially located goods are assigned a value which can be accessed by any agents within range – a kind of “boost” that contributes to the calculation of satisfaction with their neighbourhood. The “public goods” of this model are different from the venue model we present below in a number of crucial ways. First, access to cells with a “public good” is limited by the same distance measure that defines an agent’s neighbourhood. This leaves out any chance for agents to travel or commute to a destination beyond their local surroundings and suggests a challenge for analytically parsing out the influence of neighbours from that of the “public good”. Second, their “public good” is represented by a fixed utility value while we consider instead the interaction between the agents who visit such a location. Finally, and on a related note, our venue is not necessarily conceived of as a “good” of any sort. We are equally interested in circumstances where venues can have strongly repulsive influences on surrounding agents. Notwithstanding these differences, we share the authors’ interest in a third kind of cell (in addition to empty cells and those occupied by individuals), and arrive at some related findings in the studies we present below.

Related work suggests that venues and other aspect of urban form plays a significant role in community and urban formation. Menchick (2017) brings together several strands of ethnographic research on the importance of venues (e.g. Feld 1981, Mische 2008, Hughes 1971, Zussman 2004, Delbridge and Sallaz 2015). In this tradition, a venue “is a place people visit repeatedly to recognize the same problems, do the same tasks, and achieve the same kinds of solutions” (Menchick 2017: 3). As such, they “tug” people into (or away from) certain roles and relationships, thereby organizing social behavior. Grazul (2016) adds that venues organize social life through two crucial processes, they are i) foci for social interaction and ii) finite. The former (i) draws people together for distinct tasks and goals, the latter (ii) produces constraints based on the number and distribution of venues. A city with one church, one gas station, and one grocery store, all located at the center of town, provides very different opportunities for interaction than one with dozens or hundreds of venues distributed throughout multiple neighborhoods. Gieryn’s influential work (2002) on “What Buildings Do” highlights how buildings stabilize social life just as much as they are themselves structured and continually reconstituted through the kinds of people and activities they support. In various overlapping ways, these research lines point toward venues as crucial but neglected local mechanisms structuring larger patterns of behavior.

Other work, both qualitative and quantitative, focuses more squarely on the relationship between built form and urban segregation and integration dynamics. Martinez’s ethnographic study of the activities of Italian American Catholic parish members in a predominantly Latino neighbourhood offers a productive example (Martinez 2017). In this research, the author studies the “making, marking, and marketing” strategies for asserting identity on place – a church shared between the two ethnic groups – in the context of neighbourhood succession. Likewise, in their study of Jewish communities in Toronto, Fong and Harold note the importance of synagogues as both institutional grounding and symbols of collective identity (Fong and Harold 2017:355). They point out that while this is a particularly pressing matter for orthodox communities (“to ensure they could walk to services on the Sabbath”), it remains relevant in residential choices for non-orthodox Jews as well. Elizabeth Roberto has developed a method for measuring residential segregation which accounts for the relevance of built form such as road connectivity and barriers to travel (Roberto 2015), while others have examined how geographic space organizes social fields (Martin, Slez, and Borkenhagen 2016, Leschziner and Green 2013) and social networks (Butts et al. 2012). Other studies of segregation have begun to account for the separation of groups beyond their places of
residence. Atkinson and Flint, in their study of gated communities in England (2004) refer to this as “time-space trajectories of segregation” – an extension of the logic of separation into the territories, objectives, and corridors of everyday life. Others, for example Browning, have employed the concept of “activity spaces” to examine the extension of segregation beyond place of residence (2017). Logan’s 2012 review of “spatial thinking in social science” brings many of these themes together.

This brief review indicates the importance and complexity that venues can hold in neighbourhood formation, and the increasing acknowledgment of their relevance for understanding the dynamics of segregation. They also point toward some of the key questions and assumptions about the relationship between venues and individual behavior that our simulation model is designed to allow us to experimentally probe. In fact, Schelling himself pointed in this direction, even if he, and the subsequent implications of the evacuation, “spatial thinking in social science” brings many of these themes together.

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While we share these authors’ view that austere models can be more intellectually productive than a blind pursuit of fidelity, the design of a particular simulation must inevitably be determined by the phenomena and hypotheses at hand. Given our stance that urban form can play a salient role in segregation dynamics, we have designed a simplified model of spatially located venues to pursue our overarching research question: when do venues reinforce segregation, and when do they support integration? Building upon the relevant qualities of venues identified in the literatures reviewed above we probe the implications of the fact that venues are i) foci of interaction and ii) finite by varying i) their interaction rules and ii) their number and distribution. The simulation framework allows us to precisely formulate these assumptions and test a wide range of different scenarios to determine critical thresholds and tipping points. We find that venues not only mediate the distinctive dynamics Schelling observed, they also generate distinctive spatial order lacking in Schelling-style models. In other words, venues enable a generative model of urban social structure, in line with Epstein’s (1999) dictum: “if you didn’t grow it, you didn’t explain it.” We identify specific mechanisms through which this order is produced, such as “locking in,” “bootstrapping,” “action at a distance,” “bridging,” “cascading”, “cooptation,” “evacuation,” “dispersion,” and “abandonment.” Moreover, and perhaps most importantly, we show that in some situations strategic placement of venues can alter and disrupt settled segregation patterns, without requiring any fundamental transformation in the motivational basis of individual behavior (e.g. by introducing a proactive desire for diversity). This is a result impossible to achieve under traditional Schelling assumptions that ignore built form, and indicates scenarios where urban planning interventions may have a reasonable likelihood of disrupting entrenched patterns of segregation.

**METHODOLOGY**

**Venue:**

A pervasive fact of contemporary life is that we spend much of our time in buildings. While this is an obvious truism, the literature reviewed above points toward the far-reaching but relatively underappreciated implications it holds for social life in general and urban life in particular. The buildings of our everyday lives include the places where we live, but also the places of our work and leisure activities. The heterogeneity of cities is such that these latter places might be located at a distance from the former: we travel across town to visit restaurants or commute downtown to our offices. While we might feel obliged to visit some of these places, such as schools, others, like coffee shops, are more voluntary. Some can be seen as exclusive places, for example a social club requiring membership, while others, like grocery stores, are
open to any visitor. While our sense of belonging and shared identity is undoubtedly influenced by the place where we live and the surrounding neighbourhood, our assertion is that it might equally be shaped by these ancillary places of everyday life.

To investigate these statements, we implement a version of Schelling’s simulation in which venues are a second kind of agent alongside the typical individuals. As in Gieryn’s (2002) ethnographic depiction, in our simulation model, buildings “do” things. Like individual agents, venues occupy a single cell and are affiliated with a particular group. Just as the model has a parameter representing the maximum distance individuals will consider as part of their local surroundings, we introduce a second numerical input to represent the maximum distance they are able to travel to a venue. We can also think of this distance as the catchment area of a venue by measuring outwards from the venue’s position. At each time step, and for each venue within an individual’s travel range, a decision procedure is run to determine whether a visit occurs. Each venue retains a list of the individuals that have visited during a particular time step. When an individual evaluates the suitability of their location, the attendance lists of any venues it has visited are added into the calculation. Note that in our model, only individuals who visit a given venue are influenced by it. An individual must enter into a venue to know who is attending and to be influenced by them. In other words, individuals do not find the mere presence of a venue to be inherently positive or negative. If an individual decides to move, they judge the suitability of potential destinations by considering the surroundings of this location as well as any local venues that they would be likely to visit, should they decide to move. We can think of this as touring through the local venues before opting to move somewhere new.

![Figure 2](image)

Figure 2: [1] A set of individuals and a blue venue. Each individual has its own surroundings and the venue has a catchment area that is determined by the maximum travel distance. [2] If this venue is completely obligatory and exclusive, every blue individual within the catchment will visit during each time-step. Blue individuals beyond the catchment area (such as ‘C’) are unable to visit. Evaluating their positions, ‘A’ has 4 like-neighbours of 11, but also 18 like-neighbours added from the venue, yielding a score of 22 of 29. ‘B’ has 3 like of 8, but also 18 from the venue, resulting in a score of 21 of 26. ‘C’ has 2 like-neighbours of 8, with no contribution from the venue because it is unable to visit. [3] If ‘C’ moves this turn, it will consider destinations within the catchment distance of the venue and also beyond in a random order. In evaluating the former, such as location ‘1’, it will consider the influence of individuals from the venue, making it a very good destination, while ‘2’ which is just beyond the venue catchment will not benefit from the additional count, and will hence not be a likely choice.

Individuals are influenced in the decision to visit venues by the rules governing social interaction there. While Menchick (2017) and others point to a wide range of potentially complex rules, we seek to build our model on a small number of simple rules, and observe their potentially complex interactions. Accordingly, venues in our model have two rules for who associates there: exclusivity and obligatoriness. We understand these two rules to arise as immediate responses to the basic question of urban venues: who attends?

The exclusivity (measured from 0 to 1) of a venue represents the openness of that venue to individuals of other group-affiliations. For example, a completely exclusive venue (1/1) can only be visited by individuals

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2 For convenience, we follow the literature in referring to this as the cell’s neighborhood. However, in our Discussion section below we expand on the limitations of this term for our work, since the concept of neighborhood is itself a research question.
of the same group, a completely open venue (0/1) can be visited by any individuals at all, and a range of exclusivity values between will lead some but not all individual of other groups to visit. Along with the venues’ exclusivity, each individual has a corresponding internal value that we can think of as their adventurousness. More adventurous individuals are likely to visit more exclusive venues of other groups, while the less adventurous will only visit their own venues and especially welcoming venues of other groups. Relying on a similar calculation, obligatoriness represents the degree to which a venue must be visited by individuals within the travel distance. Venues can range between completely obligatory (1/1) in which case all individuals who are otherwise able to visit will visit, and imposing absolutely no obligation to visit (0/1), in which case none will do so. This obligatoriness could be a function of social pressures, basic human needs, etc. Keeping with the logic of the exclusivity parameter, individuals have an internal value that ranges from indifferent (0/1) to committed (1/1) in terms of these obligations.

Figure 2 illustrates these basic rules visually. Appendix 1 lays them out in more formal detail in the context of the complete simulation pseudocode. Tables 1 and 2 further clarify their meaning. Table 1 shows examples of types of venues that could correspond to various combinations of exclusivity and obligatoriness, such as coffee shops (low exclusivity and obligatoriness) or orthodox churches (high obligatoriness and exclusivity). Table 2 maps individual attributes (commitment and adventurousness) to venue attributes (obligatoriness and exclusivity) to show how the likelihood of participating in a venue varies across their combinations. These parameters codify in simple terms how venues serve as focal points for interaction in our models. Our simulation experiments examine how variations in these parameters affects the kinds of segregation and integration dynamics Schelling observed. In addition to varying the interaction rules governing individuals and venues, we also vary the number of venues and their physical distribution. This combination of “planned” and “unplanned” organization is a key contribution of our model that captures a vital aspect of urban formation.

<table>
<thead>
<tr>
<th>Less Exclusive</th>
<th>More Exclusive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee Shop</td>
<td>Golf Club</td>
</tr>
<tr>
<td>Park</td>
<td>Social Club</td>
</tr>
<tr>
<td>Grocery Store</td>
<td>Orthodox Church</td>
</tr>
<tr>
<td>Bus Shelter</td>
<td>Private School</td>
</tr>
</tbody>
</table>

Table 1: Examples of venues sorted by Exclusivity and Obligatoriness

<table>
<thead>
<tr>
<th></th>
<th>Low Obligatory, Low Exclusivity</th>
<th>High Obligatory, Low Exclusivity</th>
<th>Low Obligatory, High Exclusivity</th>
<th>High Obligatory, High Exclusivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Committed and adventurous</td>
<td>Likely</td>
<td>Likely</td>
<td>Likely</td>
<td>Likely</td>
</tr>
<tr>
<td>Committed and unadventurous</td>
<td>Likely</td>
<td>Likely</td>
<td>Unlikely</td>
<td>Unlikely</td>
</tr>
<tr>
<td>Indifferent and adventurous</td>
<td>Unlikely</td>
<td>Likely</td>
<td>Unlikely</td>
<td>Likely</td>
</tr>
<tr>
<td>Indifferent and unadventurous</td>
<td>Unlikely</td>
<td>Likely</td>
<td>Unlikely</td>
<td>Unlikely</td>
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Table 2: Likelihood of different individuals visiting different venues. Commitment and adventurousness are internal individual-values that correspond with the venue parameters Obligatoriness and Exclusivity, respectively.

Our general procedure is as follows: We undertake four studies of increasing complexity. For each study, we first show the simulation settings and venue distribution. To summarize results from many runs, we introduce a visualization technique for envisioning results across a two-dimensional parameter space, measuring the Concordance, or relative degree of integration and segregation (see Appendix 3), for each combination of the variable input parameters. Images of particular outcomes highlight key results at specific positions, while videos (viewable at hyperlinks included in the text) show illustrative examples of unfolding processes. Study 1 begins by replicating Schelling’s model, before investigating how the introduction of venues alters it through the number, arrangement, and travel distance of venues. Study 2 considers social rules governing who visits venues by varying the exclusivity of venues. Study 3 examines how venues operate among populations of different sizes, and introduces a new analytical technique designed to highlight what we call “expanse.” Study 4 investigates whether and under what conditions
building or relocating venues can disrupt settled patterns of segregation. Here we develop a novel application of a genetic algorithm, which systematically searches across all of the parameters in our simulation world to find the optimal locations and settings at which venues have their maximal impact. Across our studies, we are focused on observing how venues can produce new configurations of urban segregation or integration that are not found in Schelling’s original model.

FINDINGS

Study 1: Spatial Configurations of Venues
While the world of Schelling is homogeneous, features of urban form such as topography, roads, and buildings make actual cities highly heterogeneous. In Study 1 we introduce the venue model as a type of heterogeneity and consider the role of different urban configurations on the resulting clustering of groups. By evaluating linear, radial, and core-periphery layouts in terms of a range of intolerance and travel distance values, we identify key thresholds in the parameter spaces, the stability or volatility of the outcomes across multiple runs, and visual patterns of agglomeration. These idealized configurations allow us to see the influence that venues can have on the simulation outcomes while also speaking to a set of different shapes of neighbourhood that can emerge from the interplay of simulated agents and “top-down” or planned urban forms.

Study 1.0: Venues and Space

Figure 3: Study 1.0 simulation settings and resulting parameter space. See Appendix 3 for more details on “Concordance”. For additional simulation settings, see Appendix 2.

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3 With edges and corners presenting an exception for non-toroidal simulation worlds such as ours.
Figure 4: Results sampled from the first study, comparing different values for individuals’ intolerance (x) and the maximum travel distance to venues (y). In the first view, [1], we see classic Schelling-style segregation, [2,3] the influence of venues as travel distance increases, [4] an area of low intolerance, [6,7] “locked-in” situations that in [5,8,9] are “unlocked” by the influence of venues, which “bootstrap” new neighborhoods.

In Study 1.0 (see Figure 3, Figure 4) we have positioned two venues (each associated to one of the two groups) just north and south of the world’s center. These venues are entirely exclusive and obligatory. We run the simulation while varying the individuals’ intolerance levels from 0 to 1 and their maximum travel distance from 0 to 50. The center and right panels of Figure 3 represents the simulation’s parameter space. Squares represent simulations run with these different combinations of inputs. In the center, each square is assigned a grayscale value based on the average concordance of each cell in the simulation with its immediate surroundings. Since we repeat each combination ten times with different random initial distributions of agents, the results are averaged to arrive at a single grayscale value (see Appendix 3 for more detail). Here, white squares are highly integrated outcomes, while darker squares indicate simulation worlds that are increasingly segregated. In the representation to the right, each square is assigned a value based on the standard deviation amongst the ten results sharing the same parameters. We can see in this case that the results are very stable across multiple runs for most of the parameter space. The views in Figure 4 show the simulation outcomes for particular combinations of input parameters. Numerical labels in the parameter space and below the views link these together, and allow us to refer to them directly.

[1] Classic Schelling Segregation: Note the bottom row of the parameter space, where the maximum venue travel distance is 0. Since a value of 0 means that venues cannot be visited, even by their immediate neighbors, this line of the parameter space acts as a useful reference to a Schelling simulation without venues. We can compare other areas of the parameter space to this line in order to see how the venues have impacted the simulation outcomes. Looking at this row of squares, we see white squares on the left side, where individuals have such a low intolerance that they are satisfied with their randomly mixed initial position. Moving to the right, the classic Schelling tipping point is represented by the increasingly dark squares starting from an intolerance of 0.35. As intolerance increases, the concordance of each cell with its neighbors increases, or put otherwise, segregated neighborhoods emerge. As we move further to the right, and intolerance continues to increase, we find another set of highly mixed outcomes. This mixing results from individuals being “locked-in”: they are unsatisfied with their initial locations and yet none of the available cells are suitable to motivate a move. While Schelling’s insight is that relatively low levels of individual intolerance can lead to segregation at a macro scale, in these cases the reverse is also true: high levels of individual intolerance lead to macro diversity. Comparing the two kinds of mixing to the left and right of first row is hence a matter of accounting for the individuals’ satisfaction with their mixed
neighborhood.

[2,3] The Influence of Venues on the Classic Schelling Segregation: Focusing on the intolerance levels that yield segregated outcomes, we can now consider how the situation is altered by venues. Reading upwards from [1], each square is a lighter shade than the one before, meaning that the outcomes are increasingly mixed. By looking at [2], we can see why this is the case: even while the general pattern is towards segregation, the area within travel distance of both venues is highly integrated. In this area, individuals are comfortable with a more diverse neighborhood because they participate in a venue with many individuals of their group (see Video 2 and Video 3 for a comparison of the same initial distribution of agents with and without venues). Even with relatively high levels of intolerance, it is only the individuals without access to the venues that feel compelled to segregate. As the maximum travel distance increases, the size of this mixed area also increases. Eventually, as in [3], the maximum travel distance encompasses the entire simulation world, at which point the importance of the venues entirely outweighs each agent’s local neighborhood.

[4] Area of Low Intolerance: While the area of low intolerance to the left of the parameter space visually resembles [3], the two are importantly different. In [3], individuals are unsatisfied with their initial random neighborhood, but access to the venue compensates for this fact. While in [4], when intolerance levels are very low, the positive impact of the venues is unnecessary because each individual is already satisfied with their neighborhood and hence none feel compelled to move.

[5,6,7,8,9] Unlocking Distributions with High Levels of Intolerance: As we have already noted, there is a third area of mixed outcomes in the lower right of the parameter space. In these runs, individuals are locked-into their initial unsatisfactory position. As the travel distance increases [6], these unsatisfied agents are drawn towards any available cells within range of the venues. Like the individuals near the center of [2], they are content with the mixed surroundings near the center because these cells provide access to many members of the same group at the venue. Unlike [2], the level of intolerance in [6] leads to a significant pressure towards the center, evidenced by the high density (the absence of vacant cells) within range of the venues. This intolerance also means that the remaining individuals beyond the range of the venues are still “locked-in”: they remain unsatisfied with their mixed surroundings.

Between [5] to [6] and [7] to [8] we can see a curved threshold in the parameter space. On one side of this threshold, individuals who are beyond the maximum travel distance from the venues nonetheless succeed in organizing themselves into segregated neighborhoods. For example, at [5] we can see a typical pattern of Schelling clustering beyond the overlapping areas of the venues, while at [8] and [9] the entire neighborhood is organized according to the travel distances of the venues. These cases are characterized by a highly mixed core that resembles Anderson’s “cosmopolitan canopy” (Anderson 2011), where access to the venues enables individuals to accommodate much more diversity in their immediate surroundings, but also produces a highly segregated periphery. By leveraging all of the like-individuals within travel distance of the venues as potential neighbors, the nearby empty cells become suitable destinations, drawing agents in from the periphery. The venues “bootstrap” new neighborhoods, of which they become the center points. Finally, along this threshold curve – with the right combination of travel distance, tolerance, and initial conditions – the venues break the “locked-in” condition. We can see in [5] and [8,9] that all of the movement inwards towards the venues has the side effect of opening up satisfactory positions around the periphery. Not only do venues produce combinations of integrated and segregated neighborhoods, they even indirectly influence the decision-making of individuals beyond the maximum travel distance. We will refer to this tipping outwards from the venues’ catchment areas as “action at a distance”.

Study 1.1: North South
In Study 1.1, we multiply the two venues from Study 1.0 to produce two horizontal linear arrangements. In this case, the venues are withdrawn further from the horizontal centerline of the simulation world. Once again, the simulation is run across a range of travel distances and intolerance values in order to compare results between the two studies. While the general distribution of segregated results is similar, the significant differences in this study are discussed below.

[1,2] The Influence of Venues on Schelling Segregation: The impact of venues is much the same here as in Study 1.0, except for the multiplicative factor of having more venues. In other words, with six venues, there is simply more area of the simulation world that is within a venue catchment for a given maximum travel distance. Increasing the number of venues and increasing the maximum travel distance both push the tipping point towards a higher intolerance, leading individuals to be more comfortable with diverse surroundings in a case such as [2].

Figure 5: Study 1.1 simulation settings and the resulting parameter space. See Appendix 3 for more details on “Concordance”. For additional simulation settings, see Appendix 2.

Figure 6: Some results for the North-South distribution. Between [1] and [2] we once again see the influence of venues on classic Schelling-style segregation, at [3], “bridging” between venues of the same group even beyond their catchment areas, and from [4] to [5,6] the unlocking, segregation, and finally integration driven by the linear arrangement as travel distance increases.
[3] Bridging between Venues: While Study 1.0 focussed on the interaction between two venues associated with different groups, here we are also able to observe interactions between multiple venues of the same group. For example, with relatively high levels of intolerance but limited travel distances, we find a kind of “bridging” that can take place between venues. Even though the catchment areas of these venues do not overlap, they appear to coordinate in order to produce contiguous segregated zones. The venues yield highly segregated surroundings, which continue “tipping” outwards beyond the catchment. While related to the “action at a distance” from Study 1.0, where we noted an unlocking of agents, here it is more clearly a coordination of agents between venues, even while they visit neither venue. This bridging can be seen in Video 4, where connections between venues begin early in the simulation and are increasingly reinforced by the process of segregation.

[4,5,6] Increasing Travel Distance with High Intolerance: When the intolerance is higher, as in [4], we do not see this coordination effect. Instead, we find a similar combination of dense catchment areas around venues and “locked-in” individuals beyond that was observed in 6 and 7 of Study 1.0, Figure 4. Increasing the maximum travel distance, in [5,6] we see the same overwhelming effect of the venues, where at first [5] segregation reigns and then [6] diversity is supported by the thickening horizontal overlap of catchment areas. Comparing this trajectory of increasing travel distance at high intolerance to Study 1.0, we can see that the venues break the ‘locked-in” condition earlier and yield entirely integrated results slightly later. These differences can be accounted for by the fact that there are more venues and these venues are spaced further apart vertically. Comparing [5] and [6], it is striking that the same venues can generate complete segregation and increasing integration depending on the maximum travel distance parameter. These studies are strong examples of the effects of the number, distribution, and reach of venues.

Study 1.2: Radial

![Figure 7: Study 1.2 Simulation settings and resulting parameter space. See Appendix 3 for more details on “Concordance”. For additional simulation settings, see Appendix 2.](image)
Studies 1.0 and 1.1 produced a range of outcomes combining segregation and integration to different extents throughout the simulation world. Areas of integration developed in the overlap of venue catchments while segregation resulted elsewhere, leading to a simple core-periphery distinction. In Study 1.2, we introduce a radial arrangement of venues, where overlapping catchments will first occur around a ring rather than in the center of the space. In this study, we are interested in the development of the core area: will it remain integrated in a similar manner to the cores of earlier studies, or will it be occupied entirely by one of the groups, and how will this dynamic be influenced by the surrounding venues? Across multiple iterations, we find this area to exhibit a high degree of sensitivity to the initial random distribution of individuals. This is revealed in the Predominance representation of Figure 7, which counts the extent to which the one group exceeds the other in occupying the central area delineated by the venues. Unlike the tipping of neighbourhoods in the abstract grid of Schelling’s model, or even the simple distributions described in the first studies above, the radial model is made more interesting insofar as the contested core – with its privileged access to the whole ring of venues – represents a distinctive urban area that would be desirable for a group to occupy. Here we see that the same sorts of conditions which give rise to the “cosmopolitan” diversity of the urban core also can make it into a zone of competition and contestation in which outcomes are uncertain and variable.

[1,2,3,4] The Influence of Venues on Schelling Segregation: We are by now familiar with the changes caused by venues to the original Schelling tipping point. Here we find similar results to earlier studies, except that the tendency towards integration begins much earlier as a result of the number and distribution of venues. This general feature can be observed in how compressed the segregated area of the parameter space is compared to the earlier studies. In the radial arrangement, a striking difference is the presence of a segregated core area [2,3] that progressively disappears [4] as travel distances increase and the venue catchment areas grow.

[5,6] The Contested Core: At higher levels of intolerance, the role of the venues in organizing individuals becomes increasingly legible. For example, at [5], the overall pattern is coordinated around the ring of venues. In conditions such as these, a variety of different outcomes emerge within the core area. While at [5] we can see agents “bridging” between some blue and red venues by occupying part of the core, at [6] we see the blue venues “bridging” directly through and dominating the center area (we see a similarly
contested core play out in Video 5). At the same time, in the periphery of [5,6] we find further demonstrations of “action at a distance” with individuals organizing into clusters that radiate outwards from the core. Even though they yield very similar concordance values, these two outcomes represent significantly different urban configurations in terms of the predominance of one group or the other within the core area.

[7,8,9] Unlocking Radial Arrangements: Just as in the previous studies, the radial venues are able to unlock individuals from initially highly intolerant “locked-in” positions such as [7]. As we can see in [8,9] this unlocking can generate both segregated areas separated by vacant cells, integrated areas around the ring where venue catchments overlap, and a contested core.

Study 1.3: Mixed Core-Periphery

Figure 9: Study 1.3 Simulation settings and resulting parameter space. See Appendix 3 for more details on “Concordance”. For additional simulation settings, see Appendix 2.
In the first studies, a frequent outcome was the tendency towards densely integrated central districts with a segregated periphery. In Study 1.2, we sought to override that tendency with a radial arrangement, leading to a contested core. Now, we ask instead how the core-periphery patterns might be influenced or modified if they are reinforced by the distribution of venues. In this final study of venue configuration, we simulate a core-periphery urban form by distributing venues of both groups evenly within the center of the grid and a single additional venue in each corner, with opposite corners given over to the same group. In Figure 9 and Figure 10, we evaluate these simulations while once again varying maximum travel distance and levels of intolerance.

[1,4] The Persistence of Segregation in the Core: In these two examples of low travel distance, we see the tension between a desire to segregate on the part of individuals and the dense integration of venues. For example, note in [1] the diagonal pattern of blue individuals “bridging” between venues, as well as small pockets of red clusters. Towards the upper right of the core area, we can see one red venue which holds only a few red agents within a larger cluster of blue. In [4] and Video 6, where intolerance is higher, the pattern of venue-driven segregation in the core is more evident, with the exception of one red and one blue venue left of the center. These two venues have failed altogether to sustain individuals from their groups. It is important to bear in mind that since these venues are entirely exclusive, it is not that the opposing group is occupying them. Instead these are cases where the positive influence of the venues on its own group is insufficient to support the location. While the distribution of segregated individuals within the core is determined in large part by the venues, we see exceptions in both [1] and [4].

[2,5] The Integrated Core: As the maximum travel distance increases, the core changes from small segregated clusters to a single integrated area. This is in keeping with our findings in Study 1.0 and 1.1 – that overlapping catchment areas of exclusive venues support integration. Beyond the core we continue to witness a segregated periphery, with (particularly in [5]) the corner venues beginning to provide coordination to the distribution of individuals.

[3,6] Action at a Distance in the Periphery: Finally, as the maximum travel distance continues to increase, the segregated periphery shrinks relative to the integrated core, but also becomes increasingly organized by the outer venues. The core-periphery pattern of earlier studies is repeated here, but with the “action at a distance” being coordinated by a set of peripheral venues rather than as a tipping out from the core.

[7,8,9] Core vs. Periphery: As travel distance increases, the growing core that we have observed tends to predominate, leading to increasingly integrated results. There are, however, a set of simulations with very high levels of intolerance, in which the segregated periphery pushes back against the integrated core. At the highest levels of intolerance, and with just enough travel distance to avoid “locked-in” outcomes such as [7], we can see the tension between solutions where (even with the same maximum travel distance) either the integrated core predominates as in [8] and Video 7, or the segregated periphery does, as in [9].

Summary
In the first study, we consider different spatial configurations of venues in order to determine what influence they could have on patterns of integration and segregation. In a variety of different ways, venues are demonstrated to support combinations of both integration and segregation and to modify and even override the dynamics Schelling observed. Additionally, we have noted the “unlocking” and “bootstrapping” of neighbourhood formation in highly intolerant populations, as well as the “bridging” and other “action at a distance” influences of venues beyond their catchment areas.

**Study 2 – Exclusivity and Sharing**

![Figure 11: Simulation settings and resulting parameter space. See Appendix 3 for more details on “Concordance”. For additional simulation settings, see Appendix 2.](image)
Applying the linear venue arrangement from Study 1.1, we begin to experiment with venues that are not entirely exclusive. What effects are produced by allowing interactions between individuals of different groups within venues? Recall that the exclusivity of venues is measured as a value from 0 to 1, or, entirely open to entirely exclusive. In this study, we limit the variations in exclusivity to the blue venues, while varying the intolerance level of both groups, in order to observe the introduction of some red agents into blue venues.

[1,2,3,4] The Tipping of Non-Exclusive Venues: Just as individuals can coexist in an integrated neighborhood with sufficiently low levels of intolerance, so too can they co-occupy venues with the right combinations of tolerance and exclusivity. Since exclusivity controls the fraction of individuals from other groups who can attend a venue, as exclusivity increases, those few individuals of another group who are adventurous enough to attend must also be quite tolerant in order not to be scared away. We can see this relationship in the sloping threshold up and towards the left from [8] to [4] in the parameter space above. On one side of this threshold [1], individuals are largely integrated, both in the space of the simulation cells and in their attendance of blue venues. However, as either the level of intolerance [2] or the exclusivity [3] increases, the situation changes dramatically. With greater intolerance, red agents visiting the blue venues are unhappy with the large number of blue agents they meet and hence relocate to predominantly red areas. The departure of the more adventurous red agents begins a critical mass event, "cascading" over time and leading eventually to the departure of even those red agents who had not visited blue venues. Without an increase in intolerance, high levels of segregation can also develop when the blue venues are more exclusive. For example, in [3], fewer red agents will visit blue venues. Even if relatively tolerant, the few who attend will decide to leave as a result and initiate the "cascading" departure of all red individuals. Finally, note that when blue venues are yet more exclusive, fewer red agents attend and then leave. The fewer such red agents, the less likely their behaviour is to set-off a cascade amongst the others. This relationship is visible in the change of direction around [4] where the parameter space threshold begins moving upwards towards the right: with fewer red agents scared off by blue venues, intolerance must be higher for their departure to set off a larger cascade. Overall these runs yield the intriguing insight that in some cases decreases in a venue’s exclusivity can increase segregation, by bringing individuals into interaction who would not otherwise have met, and in turn setting off a chain reaction.

[5] “Locked-In” with Low Exclusivity: We have seen in [1,2] that low levels of exclusivity can lead to either integrated or highly segregated outcomes depending on the level of intolerance. In [4] we see that low exclusivity can also produce another example of a “locked-in” distribution. Because there are many blue and red agents visiting the blue venues, these venues are unable to attract blue agents: the blue agents are not able to “bootstrap” a neighborhood because of the mix in attendees. We can compare this to the many red agents who are meanwhile drawn to the fully exclusive red venues, in spite of the blue agents surrounding these locations. The difference between the effectiveness of the red venues and failure of the blue venues to attract agents leads to significantly different levels of density around the venues of each group.

Figure 12: Some results of the second study, comparing different values for individuals' intolerance and the exclusivity of venues associated with Group 2 (blue). The focus of this study is the sharing or co-opting of less exclusive venues by another group and the influence this has on the distribution of individuals. In the views above, we see this playing out in different ways: in [1], a sharing of low exclusivity venues amongst individuals of threshold-levels of intolerance, [2,3,4] the other side of the threshold, where the tipping of the venues leads to segregated outcomes, [5] an asymmetrically locked condition, and [6,7,8] various levels of neighborhood evacuation and co-opting by another group.
Evacuation and Co-Optation: In cases of high intolerance or extremely low exclusivity it is possible that some adventurous agents from another group can “co-opt” a venue. For example, at [7] and [8] where the blue agents are highly intolerant, the presence of some red agents at a blue venue can lead them to depart the area. Since in this scenario all of the blue agents within travel distance will visit a venue, their high intolerance, along with the presence of a few red agents at the venue, can cause the abrupt “evacuation” of the whole area by blue agents. In this situation, the venue acts as a kind of repulsive force keeping the area empty. When the local blue agents withdraw in this way, it is possible for the red agents to “co-opt” the venue and even attract more red agents from elsewhere, but the number of vacant cells in the area generally remains quite high. In cases such as [8] and Video 8, especially when exclusivity is near 0, the area around a venue can flip entirely due to a slightly greater number of red agents in the initial distribution. These runs show additional ways in which opening up a venue to “the other” can create surprising results that give insight into processes through which neighborhoods can turn-over from one group to another or cause an area to empty out entirely.

Summary
In this study, we vary the exclusivity of blue venues in order to observe interactions between the two groups within the venues as well as the surrounding cells. We find that some of the spatial patterns of Study 1, such as “cascading” and “bootstrapping” have analogues within the venues themselves in Study 2. Finally, we observe some more extreme results of relatively open venues: “evacuation” and “co-opting” caused by the mixing of highly intolerant populations within a single venue.

Study 3 – Majority/Minority Dynamics

Figure 13: Simulation settings and resulting parameter space. See Appendices 3 and 4 for more details on “Concordance” and “Neighborhood Expanse”, respectively. For additional simulation settings, see Appendix 2.
Figure 14: Some results of the third study. While the overall extent of the minority blue individuals within the world does not vary significantly from low [1,3,5] to higher [2,4,6] travel distance, the coherence of this area as a blue neighborhood changes with travel distance and intolerance. In circumstances of high intolerance [7,8,9], coherence and expanse of the minority neighborhood vary widely.

A common focus of segregation models discussed by Schelling (1971:164) and carried on by later researchers (Fossett and Waren 2005; Benenson and Hatna 2011), is the changing dynamics of the model in cases of uneven populations. Schelling himself observed that as a group becomes a smaller minority and as it becomes more intolerant, it will tend to cluster more densely. Since we have seen that increased travel distances can lead to dispersion from venues as well as increased integration, in this study, we consider how venues might influence the centripetal pull of minority groups. We use the term “expanse” to refer to the spread of the minority population cluster and present the results of this new analytical technique in Figure 13 (elaborated in more detail in Appendix 4). In a highly “expansive” outcome, a minority group covers a relatively large area in which few members of the majority are present (generally leaving significant open space). When more members of the majority group are mixed into this space, it becomes more “dispersed.” When a minority group is densely clustered in small space we can refer to it as “concentrated.”

[1,2,3,4,5,6] Minority District Expanse: In these simulations, a minority “district” emerges in the upper half of the simulation environment. When the blue agents’ travel distance is slightly greater and they are hence slightly more dispersed [3,6], the expanse of the minority district declines because there are enough open areas for red agents to comfortably remain or even to move into the spaces. Between these two travel distance values is a tipping area of outcomes that depend on the initial distribution of agents. Relatively low travel distances can yield large areas for a minority to occupy, but this also leaves many locations unoccupied [2,5] and Video 9. As travel distances increase, the minority becomes increasingly dispersed, eventually losing any contiguous segregated neighbourhood. Even with minority populations of similar sizes, very different sorts of minority districts can emerge from similar initial conditions – from districts in which minority and majority mix to those in which the minority lives alone amidst substantial amounts of unoccupied space.

[7,8] Expanse, Dispersion or Abandonment: As the intolerance of the minority group increases, a third result beyond the “expanse” of cases such as [2,5] and the “dispersion” we see in [3,6] becomes possible. At [7] and Video 10, when travel distance is relatively low and intolerance is very high, the withdrawal of blue agents from integrated areas can lead them to retreat from one venue and form a higher density area surrounding one or both of the others – minority concentration. Note that the venues are entirely exclusive
– this is not a case of “co-opting”, but instead of “abandonment”. In such cases, the role of the abandoned venues is being overridden by what Schelling identified as the general tendency for a minority group to cluster together densely. But at the same time the role of the other venues is amplified in that they tend to become the center around which minority agents cluster. Here we see underlying dynamics that tend to simultaneously generate both “abandoned” minority venues and minority concentration around venues.

[9] Unlocking Distributions with High Levels of Intolerance: Finally we note that even in majority-minority cases, a highly intolerant minority can be “locked-in” based on the absence of alternative locations. As in earlier studies (1.0 and 1.1), this situation is overcome when travel distance is sufficiently high that one or more of the venues can “bootstrap” a new neighborhood.

Summary:
In Study 3 we see that in cases of uneven group populations, venues can counteract the tendency of the minority group to cluster densely. As the travel distance of venues increases, the “expanse” of the minority cluster increases, even while the density decreases, until eventually a threshold is passed and the minority is effectively dispersed. At low travel distances and high levels of intolerance, the minority’s tendency towards a high-density cluster can lead to the “abandonment” of a venue, when the centripetal force of the group outweighs the trend to clustering closely around the available venues.

Study 4 – Stability and Intervention

One of the important characteristics of the segregation patterns generated in Schelling simulations is that they are highly uni-directional processes. Once a set of individuals have become segregated, even a significant increase in their tolerance will not undo the neighbourhood divisions that have taken shape. Setting aside modifications to the internal psychology of individuals within the simulation, we are led to ask – can venues be used as an intervention within a settled Schelling model in order to disrupt the segregated outcome? In this study, we consider the addition of venues to a venue-less simulation that has already run its course and achieved a high level of segregated stability. In order to effectively determine what input parameters and venue positions will provide the most disruption, the two-dimensional parameter spaces used to explore earlier studies is not sufficient. Here we consider a range of venue positions, exclusivity, obligatoriness, tolerance, travel distance, and neighbourhood distance values simultaneously. In lieu of our prior interval based approach, we employ a Genetic Algorithm to test and recombine values for these parameters, evaluating different combinations in terms of how much they disrupt the initial condition (measured as a drop in concordance from the initial, segregated condition).

After running the algorithm with a variety of population sizes, mutation rates, and crossover rates, the progress of each evolutionary process is mapped as a sequence of fitness values to the chart in center of Figure 15. Here, movement towards the right along each thread indicates the progress of the algorithm during one of its runs, while dropping values on the Y-axis indicate a reduction in the resulting concordance.
concordance, i.e. a more successful solution. We select the most successful interventions in order to compare their values for each input parameter in the chart to the right in Figure 15. Here, each notch along one of the spokes indicates a parameter value for one of the interventions, and hence, each intervention can be composed from a set of notches on each of the spokes. Beginning from “Tolerance” and working clockwise through the spokes, we will consider the significance of the values arrived at for each.

Tolerance: The tolerance values are clustered tightly around the value of 0.4 in successfully disruptive solutions. This value, just above the traditional Shelling tipping point, can be understood as a trade-off: it is high enough to motivate some movement by individuals, but low enough to support these same agents moving to an integrated rather than segregated destination.

Obligatoriness: The obligatoriness values tend towards 1 in disruptive solutions. Since obligatoriness controls the fraction of individuals that will feel compelled to visit venues, and since venues are the mechanism for disrupting the settled state, it follows that maximizing venue attendance will maximize the potential disruption. By contrast, introducing venues that inspire no obligation to attend them will do little to alter a segregated condition.

Exclusivity: Since exclusivity controls the number of other-group individuals who will consider visiting a venue, it regulates the new encounters between the segregated groups. It follows that an exclusivity of less than 1 is necessary in order to yield any new outcomes. On the other hand, if the exclusivity is too low, any agents within the travel distance would visit and it would hence replicate the distribution of the surrounding area. Between these extremes, and in fact closer to an exclusivity range of 0.4 to 0.6, we have circumstances in which some individuals of the opposite group will be drawn into a venue, leading to a disruption when they find that after visiting they are no longer comfortable with their location. Thus maximizing disruption involves introducing venues that are neither too exclusive nor too open but rather those that exist in a “sweet spot” between the two extremes.

Neighbourhood Distance: The neighbourhood distance is the most dispersed of the non-location parameters, with all of its distribution occurring below a value of 4. We interpret this to imply that neighbourhood distance does not play a significant role in the outcome, so long as it is sufficiently low.

Venue Travel Distance: Unlike neighbourhood distance, the venue travel distance is very tightly clustered, and tends towards the highest value possible. Since venue travel distance directly determines the number of individuals who can be affected by the venues, higher values naturally yield more disruptive results. Thus introducing venues with large catchment areas is likely crucial to interventions designed to unsettle existing patterns of segregation.

Venue Positions: Each of the two venues’ positions are encoded as an X and Y value between 1 and 50. This allows them to be located anywhere in the simulation world, even if this means displacing an individual from their initial condition. While their positions in successful solutions are mostly constrained to a narrow range, the X position of the first venue is something of an exception – with a whole range of positions that yield disruptions. In Figure 17, we summarize our findings for the venues’ positions by stepping through each cell, finding any simulations in which one of the venues occupies this cell, and colouring the cell according to the most disruptive outcome from among these simulations. In other words, we colour each square according to a best-case scenario of having a venue located there. What results is a map of the most effective positions for locating venues.
Though the central map of Figure 17 clearly illustrates that there is a broad band of more successful venue locations along the boundary area between the two segregated groups, closer inspection reveals that ideal positions tend to be slightly embedded within one of the groups, rather than in the unoccupied space between. The tight clustering of values for the other parameters suggest that the successful disruptive runs are all variations on a single strategy. This strategy involves locating a relatively open venue of a group (G1) near to the edge but slightly embedded within the segregated neighbourhood of the opposite group (G2). Because of the high maximum travel distance, individuals from the G1 are able to visit from farther away, while some closer agents from G2 are welcomed by the low exclusivity. Upon visiting, these G2 agents become less comfortable with their location, since attendance has exposed them to a greater number of agents from G1. Simultaneously, the opposite dynamic is unfolding somewhere else in the simulation world. Because of this symmetry, individuals from both groups who feel compelled to move will find new locations opening up within travel distance to an appropriate venue, leading to an exchange between two areas of the simulation world. Since the venue exclusivity is not too low, this exchange is not a complete flip – only the fraction of individuals who visit the opposite venue will relocate. These venues act like a “beachhead”, pushing away individuals from the other group and opening up spaces for their own agents to occupy. We can watch this same dynamic unfolding in Video 11.

Summary
In Study 4 we consider the possibility of applying our venue model as an intervention in highly segregated conditions. The success of the genetic algorithm in finding highly disruptive venue configurations speaks to the potential role for planning and design as a means of re-integrating a divided urban condition. It must be stressed that the successful strategy described in this study is specifically tuned to the particular starting conditions that were used. Nonetheless, this study points at specific spatial relationships between segregated groups and disruptive venues as well as the crucial balancing of parameters such as tolerance and exclusivity. Further research would be necessary to generalize these results for other kinds of initial distributions of the simulated population.

DISCUSSION
For the sake of simplicity, and in continuity with the existing literature, we have used the term “neighbourhood” throughout the paper to denote the set of nearby cells that an individual considers in evaluating the diversity of their surroundings. This use would suggest that “neighbourhood” is a straightforward concept – a function of distance – that is separable from the venues in our model. In fact, a goal of our research is precisely the opposite: to avoid an a priori definition and explore how the concept “neighbourhood” might emerge from a generative simulation model instead. In this regard, we are interested in the formation of patterns (whether segregated or integrated) out of the interactions between the individuals and venues in the simulation world. With this in mind, we can briefly survey the different contributions of venues to neighbourhood formation our model has revealed.

Across our studies, the most pervasive results are simulation outcomes that combine zones of both segregation and integration. While these combinations do not occur in the original Schelling model, prior
work has yielded similar outcomes, albeit by different means (Benenson and Hatna 2009; Wasserman and Yohe 2001). These results are interesting for us because they speak to a spatial differentiation within the simulation world, one which is also characteristic of the real world. A compelling and distinct outcome of our work is the link between the distribution and shapes of segregated and integrated areas on the one hand, and the locations of venues on the other. For example, in our first study (Figure 4), exclusive venues for both groups yield an integrated neighbourhood, in spite of very high levels of intolerance and segregation beyond. In our second study (Figure 12), where venues have low exclusivity, they increase the tendency towards segregation locally, while integration persists beyond the travel distance. In situations where individuals are locked-in and unable to find a suitable destination, venues are able to “bootstrap” a new cluster based on the like-group of individuals within travel distance. In these examples of critical mass phenomena (Schelling 1978:94), venues become the center of new, high-density neighbourhoods. Under some conditions, the neighbourhood tipping that can lead to segregation around venues propagates even beyond the travel distance of the venue. We describe these as “action-at-a-distance” and “bridging” phenomena. Finally, we see that low exclusivity venues can either be co-opted by another group, leading to the “evacuation” and co-optation or, like a “beachhead”, could be the means for a group to overtake an area. Likewise, we identify specific venue parameters that are likely to disrupt settled patterns of urban segregation. By implementing a simple model of a physical venue, we are able to illustrate this series of new neighbourhood dynamics and formations within the context of a Schelling-style model.

Our simulations are suggestive of a range of possible roles for venues in the development of neighbourhoods. It is now possible to return to our original research question: when do venues reinforce segregation, and when do they support integration? In our model, exclusive venues tend to support integration since the other group’s members ignore them. The exceptions to this are cases of high intolerance, when exclusive venues can “unlock” integrated neighbourhoods and become the centers of segregated enclaves, and “bridging”, when multiple venues of the same group form a contiguous segregated neighbourhood. As venue exclusivity drops, a number of different outcomes are possible depending on the tolerance and distribution of individuals within travel distance. Venues can either support integration if an appropriate mix of individuals visit, or, they can force out a few adventurous individuals that are outnumbered by visitors from the opposing group. In the latter case, this segregating of the venue can initiate tipping-in or tipping-out of the broader area depending on the balance of group members present. In other words, as venues become less exclusive and more inclusive, they do not necessarily encourage integration; rather, a more open world is a more complex world in which multiple outcomes are possible from similar initial conditions, often through indirect and extended causal chains.

Whether it is the result of central planning, urban design, the decision making of individual property owners, or some combination of these factors, our research suggests that the nature and distribution of venues in cities could have a role to play in the development and stability of neighbourhoods. Certain kinds and distributions of venues will encourage diverse urban communities while others could protect the comforts of shared values and collective identity. Evidently, the question of which is preferable exceeds the capacities of simulation and must lead instead to the normative considerations of an urban politics.

EXTENSIONS
Many of the classic agent-based models in the social sciences begin from a strong conceptual and implementation distinction between agents – individuals, households, etc. – and an environment or context. The latter, which Epstein and Axtell call “the medium over which agents interact” (Epstein and Axtell 1996) can be implemented as an array of values distributed on a grid (as in the case of Wasserman and Yohe’s public good) or as a cellular automata on the same grid (as in some of Portugali’s 1994 simulations). Portugali clarifies the distinction by referring to an “infrastructure cellular automata layer, describing the physical structure of the city, and a super-structure layer describing the spatial behaviour of the free agents who make up the population of the city” (Portugali 1999:4). Rather than imposing such a figure-ground approach, we have sought to make equal space for the dynamics of human and non-human entities in the simulation. While the simulation is still predicated on an underlying grid of cells, both individuals and venues are represented in our model as kinds of agent. In fact, at an implementation level, it is worth noting that both of these classes of object inherit from the same superclass, which could perhaps be considered as quasi-Latourian “actants” (Latour 1999). We have only just begun to consider the implications of this design decision in Study 4 and intend to continue in this direction. Some of the
immediate possibilities that we will explore include venue evolution and succession, as well as venue franchising and re-locating based on a continuous feedback relationship with nearby individuals and groups.

Bearing in mind our own prescription for austerity in simulation design, we nonetheless see three aspects of the interaction between individuals and venues where considering additional complexity may be a worthwhile line of future research. First, limiting individuals to have a finite available time in their schedule for visiting venues each ‘time-step’ will constrain the multiplicative effects of densely packed venues such as in Study 1.3. As a side effect, we hope to observe subsets of visitors to a venue (i.e. “morning shift” and “evening shift”) that may not even interact – a temporal segregation of venue-use to match the spatial segregation we have studied above. Second, by implementing a simplified learning process for the simulation’s agents, we will consider how the ongoing process of visiting venues could feedback into each individual’s sense of adventurousness and commitment. Third, we hope to consider the role of architectural ornamentation and signage as markers of collective visibility. These are influences that can affect individuals whether or not they enter into the venue itself. As Fong notes in the study referred to above, the presence of a synagogue can provide a sense of community and cultural familiarity even among those who do not attend regularly (Fong 2017:13) – or an object of scorn and resentment. Looking to Maurice Halbwachs, Aldo Rossi, and others, we will study the way in which such legibility develops over time and constitutes a kind of collective memory through place-making activities, modifications to built form, and the introduction of new venues.

Finally, we acknowledge that our study of venues is only a beginning to investigating the role of built form in neighbourhood formation. Any number of other aspects of cities, including roads, walls, landscapes, but also zoning restrictions and variable land values would offer interesting subjects for future study. In each of these cases, the precise influence on segregation dynamics, and also the dynamic between the ‘top-down’ design of the built form and its ‘bottom-up’ occupation by groups of individuals are fruitful avenues to explore.

APPENDIX 1: SIMULATION RULES

Attributes of Individual Agents:
- Location (initially random x,y)
- Group (either 1, red or 2, blue)
- Tolerance Level (0 to 1)
- Neighbourhood Distance (0 to world size)
- Venue Travel Distance (0 to world size)
- Adventurousness (0 to 1)
- Commitment (0 to 1)
- List of venues visited this time-step

Attributes of Venues:
- Location (x,y)
- Group (either 1, red or 2, blue)
- Exclusivity (0 to 1)
- Obligatoriness (0 to 1)
- List of visitors this time-step

Simulation Time-Step Pseudocode:
1. Establish random order of the population P
2. For each Individual A in P
   1. For each Venue V
      1. If A is within Travel Distance of V
      2. And If A feels obliged to visit V
3. And if \( A \) and \( V \) are of the same group, or, \( A \) is adventurous enough to outweigh \( V \)'s exclusivity
   1. Record that \( A \) has visited \( V \)
3. For each Individual \( A \) in \( P \)
   1. Count \( f \), the number of other agents from the same group within neighbourhood distance of \( A \)
   2. For each venue \( V \) that \( A \) visited, add to \( f \) the number of agents of same group who also visited \( V \)
   3. Calculate \( t \), the total number of agents within neighbourhood distance, combined with the total number of agents to visit the same venues as \( A \)
   4. If \( f / t < A \)'s Tolerance Level, then \( A \) will try to move
      1. Construct a list of vacant cells \( C \)
      2. For each cell \( c \) in \( C \)
         1. Using 3.1 to 3.4, determine whether \( c \) is a viable destination for \( A \)
      3. If none of \( C \) are viable
         1. \( A \) will stay at its current location
      4. Else
         1. Randomly select \( c \) from the viable \( C \)
         2. Move \( A \) to \( c \)
4. Return to 1

APPENDIX 2: COMPLETE SETTINGS FOR EACH STUDY

<table>
<thead>
<tr>
<th>1.0 – Basic Venues</th>
<th></th>
<th>1.1 – Linear</th>
<th></th>
<th>1.2 – Radial</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Group 2</td>
<td>Group 1</td>
<td>Group 2</td>
<td>Group 1</td>
<td>Group 2</td>
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<td>Tolerance</td>
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<td>Density</td>
<td>Tolerance</td>
<td>Tolerance</td>
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<td>0 to 1</td>
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<td>Exclusivity</td>
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<td>Obligatoriness</td>
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<td>1</td>
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<td>1</td>
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<td>2</td>
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<td>2</td>
</tr>
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<td>Venue Travel Dist.</td>
<td>0 to 50</td>
<td>Venue Travel Dist.</td>
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### 1.3 – Core/Periphery

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<td>0 to 1</td>
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</tr>
<tr>
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<td>Exclusivity</td>
<td>1</td>
<td></td>
</tr>
<tr>
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<td>Obligatoriness</td>
<td>1</td>
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<td>Venue Travel Dist.</td>
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### 2 – Exclusivity

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### 3 – Maj/Min

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<tr>
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<td>Obligatoriness</td>
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<td></td>
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<tr>
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<td>Number Venues</td>
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<td></td>
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<tr>
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<td>Neighborhood Dist.</td>
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<td></td>
</tr>
<tr>
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<td>Venue Travel Dist.</td>
<td>8 to 28</td>
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### 4 – Settled

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</tr>
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<td>Exclusivity</td>
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<td>Exclusivity</td>
<td>0 to 1</td>
<td></td>
</tr>
<tr>
<td>Obligatoriness</td>
<td>0 to 1</td>
<td>Obligatoriness</td>
<td>0 to 1</td>
<td></td>
</tr>
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<td>Number Venues</td>
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<td></td>
</tr>
<tr>
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<td>1 to 8</td>
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</tr>
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<td>Venue Travel Dist.</td>
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</tbody>
</table>

**APPENDIX 3: DEFINITION OF CONCORDANCE**
In order to measure the overall segregation of a particular simulation state, we look at each individual agent in the population, and ask what proportion of its immediate neighbours (Moore-1) are members of the same group. We define this fraction as the concordance of the individual. To measure the overall segregation of the simulation state, we take the average of all these concordance values. According to this logic, an initially shuffled simulation world would have a concordance of approximately 0.5, while a totally segregated world with empty cells between the two groups (as in the initial conditions of Study 4), would have a concordance of 1. In the figure above, “A” has a total of 7 Moore-1 neighbours, of which 4 are from its group. The concordance of “A” is therefore 4 / 7 or approximately 0.57.

APPENDIX 4: DEFINITION OF NEIGHBOURHOOD EXPANSE

Neighborhood expanse is evaluated using a filling rule on empty cells in the simulation world. Reinterpreting agents as coloured pixels according to their groups, empty (white) cells are filled to match the predominant colour of their Moore-1 neighbouring cells. In cases where none of the neighbours are occupied, the cell remains empty until neighbouring cells have been filled. If there is an even number of blue and red neighbours, but others remain white, the cell is not assigned a colour until all 8 neighbours are filled. If four neighbours are blue and four are red, the cell is randomly assigned either blue or red. This procedure continues until all of the white cells have been coloured accordingly. After the procedure is completed, we count the number of white cells that have been switched to both red and to blue. These two numbers provide a measure of the expanse of each group – the extent to which the group defines a coherent but dispersed cluster within the simulation world.

REFERENCES


Martinez, Juan. 2017. “This is an Italian Church with a Large Hispanic Population: Factors and Strategies in White Ethno-Religious Place Making” in *City & Community*, Vol 16, No. 4: 399-420.


