Environment and Planning B: Planning and Design 2005, volume 32, pages 657 – 672

DOI:10.1068/b31156

How ethnicity influences residential distributions: an agent-based simulation

Itzhak Omer
Department of Geography and Human Environment, The Environmental Simulation Laboratory, Tel Aviv University, Tel Aviv 69978, Israel; e-mail: omery@post.tau.ac.il
Received 16 December 2004; in revised form 17 May 2005

Abstract. This paper deals with the influence of the organization of an agent's ethnic identities on ethnic residential patterns by extending the Schelling model to include a further hierarchical level; that is, the agents' ethnic identities are organized in a two-level hierarchy (each agent belongs to an ethnic group and subgroup). Agent-based simulation reveals that the residential pattern created at given levels of ethnic residential distribution can also be a response to intolerance behaviour at another level. The simulation experiments also show that these patterns can qualitatively change in response to different intensities of intolerance at both and/or either level. However, as a result of the asymmetric nesting of agents' ethnic identities and the tangible residential patterns subsequently established, top-down and bottom-up influences are generally displayed in the following form; intolerance behaviour at the top level strengthens the segregation observed at the bottom level whereas intolerance behaviour at the bottom level tends to weaken the segregation observed at the top level. This means that intolerance-motivated segregation between a minority and a majority in a city tends to strengthen segregation between ethnic subgroups within an ethnic minority community. Conversely, mutual intolerance between ethnic subgroups within an ethnic minority tends to moderate residential segregation between that minority community and the majority population. I suggest that these conclusions can be used empirically to evaluate the consequences of individual preferences for the ethnic composition characterizing residential patterns.

1 Introduction

Members of the ethnic minority communities living in a typical contemporary city hold a set of ethnic identities (ethnic set) organized according to the ethnic groups to which they belong (Barth, 1969). From the viewpoint of an ethnic community member, these identities appear to be arranged in an inclusiveness – exclusiveness hierarchy, graded by finer to more general discrimination between the identities (Handelman, 1977). Examples of such communities include Britain's Asian community, which is multidifferentiated in terms of nationality, country of origin, religion, caste, class, and language (Robinson, 1986), and Israel's Arab minority, whose members are differentiated mainly by national identity, religion, and extended family (Ben Artzi, 1980).

Ethnic residential distributions in cities are the outcome of interactions between the residential preferences of individuals who hold ethnic sets that indicate membership in various ethnic groups. The inclusiveness – exclusiveness hierarchical organization of ethnic group identities also implies a hierarchy of the residential patterns displayed by ethnic groups, that is, spatial inclusion of the ethnic groups that occupy overlapping areas and spatial exclusion between the ethnic groups that occupy different even if adjacent areas (Smith, 1996).

Studies dealing with minority – majority residential patterns (Charles, 2000; Farley and Frey, 1994; Massey and Denton, 1989), and ethnic residential patterns among minority groups (Daley, 1998; Fainstein, 1996; Peach, 1998; Simmons, 1981) describe and explain the degree of segregation in these residential patterns as resulting from various factors, such as own-group preferences, individual and institutional discrimination, socioeconomic status, housing type, attitudes to neighbourhood diversity and job opportunities; however, they largely ignore the organization and expression of ethnicity in residential distributions. Thus, the effect of preferences for ethnic neighbourhood composition and segregation on residential patterns has been examined without reference to the relationship between the hierarchic levels of those ethnic residential distributions.

I suggest that the reason for the lacuna may lie in the absence of a theoretical explanation of the implications of internal ethnic organization for ethnic residential distributions. For example, empirical evidence has been gathered for Yaffo, an area in Tel Aviv, indicating the simultaneous decrease in segregation between its Arab and Jewish community as well as between the religious subgroups (Christian and Moslem) comprising the Arab community during the period 1955 – 95 (Omer, 2003). Nevertheless, the derivation of clear conclusions from that correlation remains difficult. Specifically, without understanding the relationship between the levels of residential distribution observed, it is difficult to say whether the decrease in majority – minority residential segregation has been influenced by the degree of segregation characterizing the subgroups in the respective minority ethnic community.

The main theoretical explanation for the influence of preferences for ethnic composition on residential patterns is suggested by the Schelling (1971; 1974) model of segregation. Schelling assumed that groups of individuals (each distinguished by one property, such as race, colour, or religion) live along a line or checkerboard and activate own-group preferences or discriminatory behaviour with regard to their neighbourhood's composition. To satisfy their residential preferences, individuals leave their current neighbourhood if it does not have the required minimum population of individuals belonging to their own membership group, for example, 'at least 1/3 of my neighbours are like me'. Analysis of the spatial patterns emerging from individuals' migration thus provides a tool for understanding the effect of individual residential preferences on residential distributions. The pioneering contribution of Schelling's model relates to its identification of the nonlinear or counterintuitive effect of discriminatory behaviour on the segregation observed. As Schelling states, "small incentives, almost imperceptible differentials, can lead to strikingly polarized results" (1971, page 146).

The Schelling model has come to represent a theoretical framework for studies dealing with the role of ethnic preferences in residential choice and their effect on residential pattern. Clark, who tested the Schelling model with empirical data, points out that this model "has provided a basic building block in our understanding of preferences, choices, and pattern" (1991, page 1). Specifically, its theoretical conclusion about the gap between own-group preferences and their consequences in residential segregation has been supported by numerous studies (see the review in Laurie and Jaggi, 2003). The implications of this phenomenon for neighbourhood ethnic composition have also been found salient for the interpretation of findings from empirical studies aimed at evaluating own-group preferences and the feasibility of creating integrated areas or preventing ethnic enclave formation in cities (Charles, 2000; Clark, 2002; Farley and Frey, 1994; Galster, 1988; Krysan and Farley, 2002; Peach, 1996; Zubrinsky and Bobo, 1996). Moreover, the robustness of the conclusions of the Schelling model was tested in more realistic environments by changing the model parameters: for example, different neighbourhood size [or 'range of vision' (see Laurie and Jaggi, 2003; Wasserman and Yohe, 2001)]. This revision (or extension) of the Schelling model led Laurie and Jaggi to the following conclusion: "Contrary to popular belief, rather modest decreases in xenophobia and/or preferences for one's own kind, *when coupled with increased vision*, can lead to stable and integrated neighbourhoods" (2003, page 2703, emphasis in original).

However, Schelling's model relates to only one ethnic identity, observed at only one level of ethnic residential distribution. In this paper I use agent-based simulation (ABS) modelling to investigate the influence of the organization of an individual's multiple ethnic identities on the ethnic residential distribution emerging during internal migration within cities. For that purpose, the simulation model applied here includes agents who hold more than one ethnic identity.

ABS modelling of residential segregation was actually initiated with Schelling's model and can be viewed as a computerized version of that model (Gilbert and Troitzsch, 1999; Laurie and Jaggi, 2003). In ABS modelling we directly interpret individual choices in terms of the agents' tolerance (or preference) for specific ethnic compositions. This allows us to explore the implications of our assumptions on the residential patterns that emerge accordingly at the macrolevel.

This modelling approach has been found to be a convenient tool for studying the dynamics of residential segregation and thus has been applied in many studies aimed at investigating the effects of demographic and behavioural parameters on this process (Benenson, 1998; Benenson and Torrens, 2004; Epstein and Axtell, 1996; Flache and Hegselmann, 2001; Hegselmann and Flache, 1998; Laurie and Jaggi, 2003; Portugali, 2000; Portugali et al, 1997). However, none of the studies performed has considered the effect of the organization of an individual's ethnic identities on residential distribution. Considered from this perspective, the Schelling model is extended in this paper to include agents who hold more than one ethnic identity.

The paper continues, in section 2, with a description of the simulation model. Section 3 presents the results of the examination; the concluding section is a discussion of the results.

2 Description of the simulation model

The simulation model was constructed by means of OBEUS (Benenson et al, 2005), the general ABS environment developed in Tel Aviv University's Environmental Simulation Laboratory (http://eslab.tau.ac.il). Following Schelling, I consider an abstract city, with the model agents located in cellular space; each cell (house) can either be occupied by one agent or remain empty. The agents can change location by migrating; their decision about where to reside depends on the properties of the agents living in their current as well as potential destination neighbourhood.

The goal of the model is to investigate the implications of the organization of an individual's ethnic identities on ethnic residential dynamics. For that purpose, the model simulates the migration of agents whose ethnic identities are organized in a two-level hierarchy. In the model, each agent belongs to one of several *groups* (minority – majority) in the larger society in addition to one of several *subgroups* that make up an ethnic minority. The resulting residential patterns emerging in the simulation enable examination of the reciprocities between the respective ethnic group and subgroup membership levels. The levels then contribute to the construction of a hierarchical ethnic residential distribution.

2.1 An agent's ethnic identities

Each agent in the model displays a set of ethnic identities. If the identity of agent A is characterized by a hierarchy that has two levels—L_a (top) and L_b (bottom) (see figure 1, over)—then the ethnic identity of A is represented as $A = (a_i, b_{ij})$, where a_i designates an ethnic group at the top level (L_a) and b_{ij} designates an ethnic subgroup at the bottom level (L_b). In this case, the structure of ethnic identities is defined by two ethnic groups at the top level and four ethnic groups at the bottom level—two subgroups within each group ($i = 1, 2$; $j = 1, 2$); hence, $a_i \in (a_1, a_2)$, and $b_{ij} \in (b_{11}, b_{12}, b_{21}, b_{22})$.

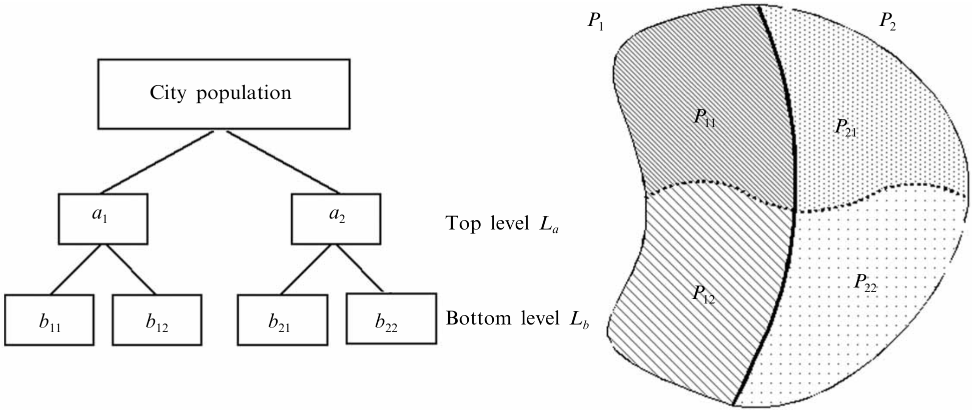


Figure 1. Schematic illustration of a two-level hierarchy of agents' group and subgroup identities and the spatial expression of that hierarchy in full residential segregation.

Given that structure, the corresponding hierarchical inclusion of spatial patterns can be described as a top level, defined as a two-component residential pattern $P_a \in (P_1, P_2)$, and a bottom level, defined as a four-component residential pattern, $P_b \in (P_{11}, P_{12}, P_{21}, P_{22})$, obtained by dividing each of the upper level residential patterns, P_1, P_2, into two separate subpatterns: P_{11}, P_{12}, and P_{21}, P_{22}, respectively.

This definition of residential distribution enables us to consider the hierarchy of residential patterns from two aspects. First, each level of the hierarchy maintains inclusiveness – exclusiveness relations between agents according to the scope of their actions. Second, each of the hierarchy branches represents a specific agent's ethnic identities.

2.2 Agents' behavioural rules

The patterns emerging from the model are the outcomes of individual behaviour and interactions, which I now detail. At each time step of the simulation, an agent makes two residential decisions (see figure 2). At the first substep, agent A (a_i, b_{ij}) evaluates his or her current location according to ethnic identity a_i of upper level L_a and decides whether to stay or move to a new residence (that is, migrate). This decision is based on *intolerance* criteria and neighbourhood ethnic composition (see below). If the agent's current location is deemed suitable and the decision is to stay, agent A participates in a second substep and evaluates his or her current position according to ethnic identity b_{ij}, of lower level L_b. As assumed in this serial hierarchic search procedure of residential choice (van Lierop, 1986), at the second substep, agent A is indifferent to identity a_i; hence, he or she refers to all level L_b identities (excluding his or her own) in a similar fashion. If the decision is to stay at this stage as well, agent A remains in his or her location for the remainder of the time step. So, agent A is satisfied (will not migrate) if and only if the intolerance criteria are fulfilled at both hierarchical levels of his or her ethnic identity. Should the intolerance criteria not be fulfilled at one or both of the hierarchical levels, agent A will decide to search for a more appropriate location. Agent A will then enter a new location according to a similar series of substeps if and only if the intolerance criteria at the new location are again fulfilled at both hierarchical levels, L_a and L_b.

The probability of leaving or occupying a location is based on *dissonance*, D, between an agent's ethnic identities and the neighbourhood's ethnic identities. Dissonance, which is calculated separately for each hierarchical level and at each time step, is defined as the fraction of neighbours in agent A's neighbourhood whose identity differs

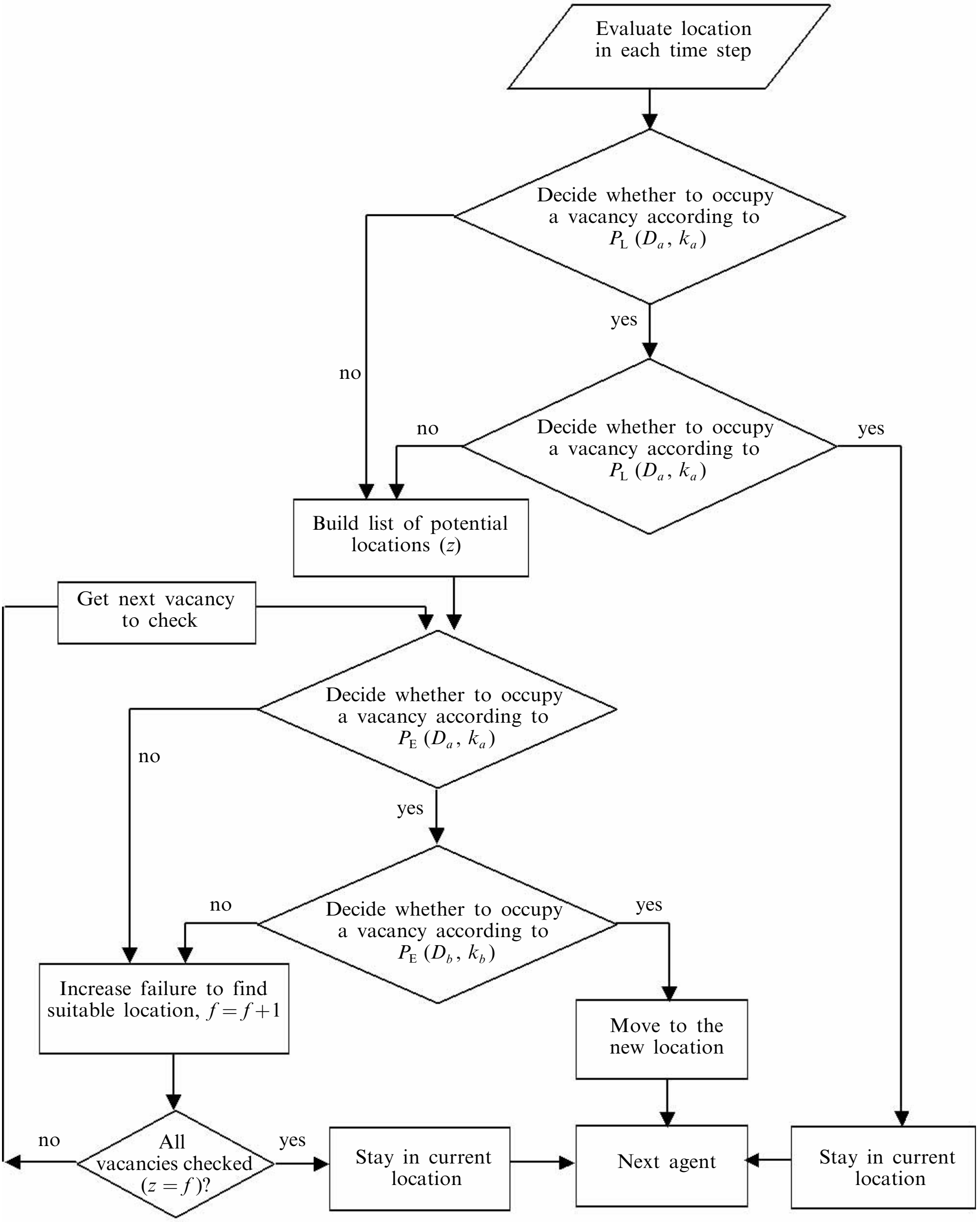


Figure 2. Agent action loop, repeated at each time step.

from A's identity. The probability P of leaving is calculated as linearly proportional to dissonance D, that is, $P = kD$; I call coefficient k the *degree of intolerance*. I assume that k is the same for each agent at a given hierarchical level; the higher k, the stronger the agent's reaction to neighbourhood dissonance D. Note that the probability of leaving a location as a result of dissonance at the upper level equals $P_L = k_a D_a$, and probability of leaving a location at the lower level is $P_L = k_b D_b$. The probability of occupying a location is, then, $P_E = 1 - k_a D_a$ at the upper level and $P_E = 1 - k_b D_b$ at the lower level. Agent A therefore decides whether to remain in his or her current location or search for a better location based on this probability at each time step.

If agent A decides to leave the current location, he or she applies to a list of potential locations that is constructed from all vacant locations at the current time step (the size of the list is determined at the initialization of the simulation). Agent A randomly chooses vacancies from the list and evaluates the probability (P_E) of occupying each. If A decides to move to one of the optional locations, his or her prior location is immediately added to the vacant locations list. Should agent A fail to find a suitable location from the list, A remains in the current location. A necessary condition for the simulation is that agents cannot leave the city.

2.3 Simulation initialization

The city area, represented by a 100×100 grid cell, is initially empty. Agents then enter the city; the first to enter always locates in the centre cell. Other agents follow the above behavioural rules within the emerging residential distribution; they react to their neighbours within a 3×3 Moore neighbourhood. The agents' in-migration rate per iteration equals 1% of the cells occupied at each iteration (current city population). The maximum number of occupied cells is limited to 90% of the total area of the city, that is, 1000 cells are always left empty. The size of agent A's potential locations list (z) constructed from the vacancies in the current time step equals 20.

The degree of segregation or concentration of the spatial patterns emerging during the simulation is measured at each time step by averaging neighbourhood dissonance D over all agents. Stated differently, each agent looks for that fraction of his or her neighbours who display different identities within the Moore neighbourhoods. The D values of all the agents at a given level are then averaged to one value, S, which represents the degree of segregation at the given level. Thus, S_a and S_b denote the segregation observed in the residential patterns at L_a and L_b, respectively. The measure S allows us to refer to the degree of segregation of a residential pattern in a way similar to that in which agents within a simulation refer or react to their neighbourhood ethnic composition.

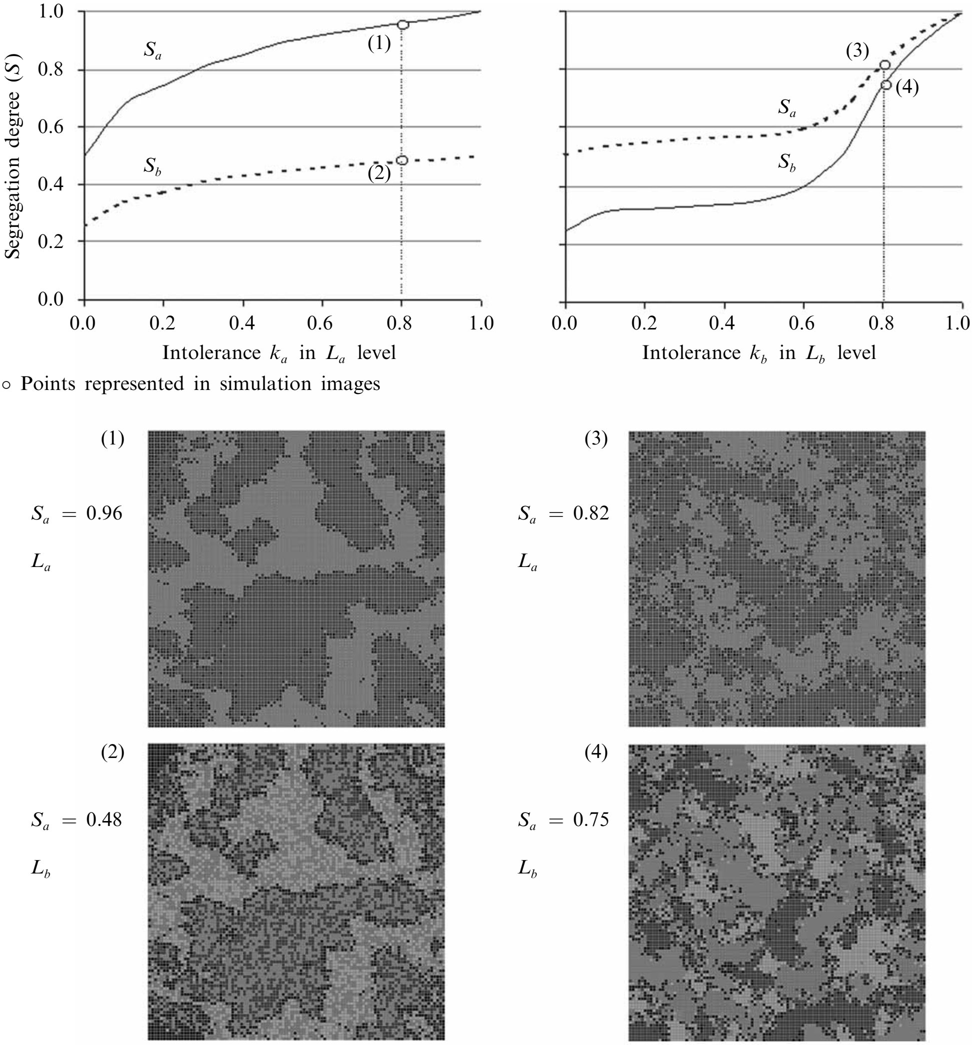
3 Residential pattern dynamics

3.1 The influence of one identity only: top-down and bottom-up aggregation effect

In order to examine the consequences of the nesting of an agent's ethnic identities, the model first simulates the residential dynamics of agents acting on one identity level only. At this stage, only two possible combinations can be realized: level L_a (top level) active or level L_b (bottom level) active (see figure 1). For that purpose, the degree of intolerance (k) is varied (between 0 and 1 at intervals of 0.1) at the active level although it always equals 0 at the passive level; that is, when L_a is active, all agents are indifferent to L_b, and when L_b is active, they are indifferent to L_a. All the results were averaged over six runs.

Figure 3 presents the residential patterns by specific intolerance values (k) observed at both levels. The results show that a hierarchy of identities resulting from actions taken at one level generates segregation at the other level. This means that the nesting of an agent's ethnic identities displays aggregation effects: actions taken at a given level have impacts on the other level and are realized through unintentional aggregation.

However, bottom-up and top-down aggregation effects are expressed in different ways. As illustrated in figure 3 by the values of segregation degree (S) and by images at selected points, the bottom-up aggregation effect [figure 3(b)] is much more significant and comprehensive, entailing strong segregation, whereas the top-down aggregation effect [figure 3(a)] is more moderate, as observed in the narrow range of segregation values found at level L_b ($S_b = 0.25 - 0.5$). This difference results from the inherent asymmetry of the nesting of the agents' ethnic identities ($b_{ij} \subset a_i$). This means that actions taken by agent A according to a bottom-level identity (b_{ij}) are necessarily also taken by a top-level identity (a_i) but not vice versa. For example, an action taken by an agent with identity b_{11} is necessarily also taken by an agent with identity a_1; however, an agent with identity a_1 does not necessarily take an action which is taken by an agent with identity b_{11} because this action could just as likely be taken by an individual with identity b_{12}.



(a) Top-down aggregation effect: L_a active ($k_a = 0.8$), L_b inactive ($k_b = 0$)

(b) Bottom-up aggregation effect: L_a inactive ($k_a = 0$), L_b active ($k_b = 0.8$)

Figure 3. Aggregation effect between hierarchical levels of residential ethnic distribution. (a) L_a active, L_b inactive: top-down aggregation creates two groups from four subgroups; (b) L_a inactive, L_b active: bottom-up aggregation creates two groups from four subgroups. The simulation images illustrate the phenomena for $k = 0.8$. The random distribution is characterized by $S_a = 0.5$ and $S_b = 0.25$. A colour version of this figure can be viewed on the *Environment and Planning* website at http://www.envplan.com/misc/b31156. Each group is represented by one colour: blue or red; each subgroup is represented by a different shade of the group's colour.

The nesting between agents' identities also implies the physical nesting of the levels of the agents' residential distribution [bottom-level patterns (P_b) $\subset$ top-level patterns (P_a)]. As a result, in situations of bottom-up influence [figure 3(b)] in which L_b alone is active, the aggregation at L_a directly and fully depends on the intolerance effective at L_b; the observed segregation at level L_a (S_a), increases from 0.5 (in a random distribution) up to 1.0. In contrast, the top-down influence [figure 3(a)] is only partial and depends on the random exposure between bottom level groups. In this case, segregation S_b depends, in effect, on the number of ethnic subgroups found in L_b that belong to the same ethnic group at level L_a. Because the ratio of the upper level to the lower level groups is 2 : 4, the expected segregation at level L_b is exactly half of the expected segregation at level $L_a : S_b = \frac{1}{2} S_a$.

The number of groups belonging to the different levels (two at L_a and four at L_b) determines the value of intolerance k that promotes segregation at a given level. At level L_b, where four groups are included in the distribution, strong intolerance is needed to create a strong segregation effect; alternatively, at level L_a, weak intolerance is sufficient for achieving strong segregation. As can be seen from figure 3, to obtain $S_b = 0.8$, an intolerance value of 0.8 ($k_b = 0.8$) is needed whereas to obtain $S_a = 0.8$, only $k_a = 0.3$ is needed. The reason for this phenomenon is quite simple: when the number of groups in a given random residential distribution increases, the fraction of neighbours belonging to the same group decreases. Hence, to achieve the same result, agent A's reactions to the other groups should be more intensive. In other words, increasing the number of groups increases the constraints that agents face when directing and coordinating their actions during a segregation process. Within a time-geography framework, this constraint is called *packing capacity*, a constraint that derives from states in which large numbers of agents act within the same time–space (Hägerstrand, 1970; Parkes and Thrift, 1980). Differential packing capacities play an important role in attempting to understand the dependency relations observed between the hierarchical levels of residential distributions, as I shall soon show.

Thus, the qualitative difference between bottom-up and top-down aggregation effects is explained by the organization of the agents' identities whereas the quantitative range and intensity of that aggregation are explained by the number of identities (that is, ethnic groups and subgroups) associated with each level. This mutual aggregation effect implies that the source of discrepancies between preferences for ethnic composition and residential patterns is not only the actions taken at one level of the residential hierarchy as posited by the Schelling model, but also a result of actions taken at other levels. It is worth noting that the aggregation effect across levels of the residential hierarchy is equivalent to the unintended consequences of the 'suspicious' behaviour observed when Sakoda's (1971) model is applied (Hegselmann and Flache, 1998). Specifically, in that model, individuals with neutral attitudes toward one another may form segregated groups driven only by negative attitudes toward a member of the other group. However, in the present case, segregation is caused by negative attitudes or intolerance toward a group located at another level.

To conclude, we should note that the assumption that only one of two levels in a hierarchy acts upon agents is not divorced from reality. Situations in which agents with the ethnic subidentities live in the same residential area, especially if they are indifferent to this subidentity, are definitely not rare. Consider the case of many French cities where members of an Algerian ethnic group live in the same neighbourhood as members of other North African communities even though they prefer to live only among Algerians. Or, consider the opposite case, in which an Algerian who wants to live among a North African population finds himself or herself in an area with a purely Algerian population.

The influence of solely one level of a residential hierarchy as examined above is, of course, a special case. Let us now examine the simultaneous influence of an agent's ethnic identities on residential distribution dynamics.

3.2 Simultaneous top-down and bottom-up interdependence

In general, the residential search process accounts for the two ethnic identities found at the top and four ethnic subidentities bottom levels of the hierarchy, with each identity stipulating its respective conditions (see figure 2). To investigate this situation, the intolerance parameters k_a and k_b varied between 0 and 1 at intervals of 0.1 (that is, $k_a, k_b = 0, 0.1, ..., 1.0$); so, $(11 \times 11 =)121$ simulation runs were observed. The results (see figure 4) show that the asymmetry between top-down and bottom-up influences is expressed in a quite different and even surprising way from the pure aggregation effect examined above. When the two levels operate simultaneously, the top level (L_a) significantly strengthens the segregation observed at the bottom level (S_b) for all possible agent behaviours, whereas the bottom level (L_b) is observed to weaken the segregation at the top level (S_a).

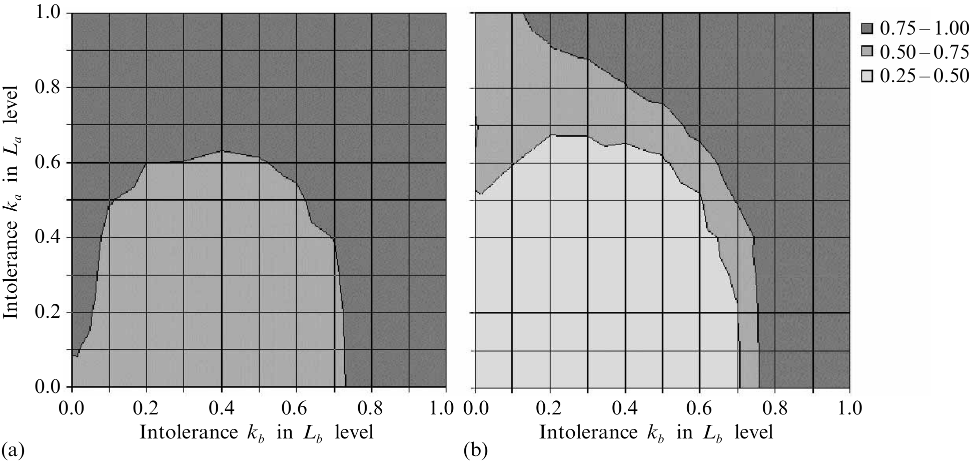


Figure 4. Interdependence between hierarchical levels of residential ethnic distributions. (a) The bottom-up effect: segregation (S_a) at top level L_a resulting from the degree of intolerance at top level L_a (k_a) and at bottom level L_b (k_b); (b) The top-down effect: segregation (S_b) at bottom level L_b resulting from the degree of intolerance at top level L_a (k_a) and at bottom level (k_b). The bottom-up effect weakens the segregation observed at L_a whereas the top-down effect strengthens the segregation observed at L_b.

The explanation for these results lies in the operation of a disaggregation effect in addition to the aggregation effect. Whereas aggregation is an expression of the inclusion of agents' identities, disaggregation is an expression of the exclusion of those identities. Because a top-level identity indicates unification and uniformity between bottom-level identities, top-down influences are expressed exclusively through aggregation. Conversely, because bottom-level identities indicate exclusion in the sense of the diversity and difference implicit in top-level identities, bottom-up influences are potentially expressed in disaggregation as well. That is, because bottom-up influences include relations of unification in addition to separation, they exert a *dual effect*: concurrent aggregation and disaggregation.

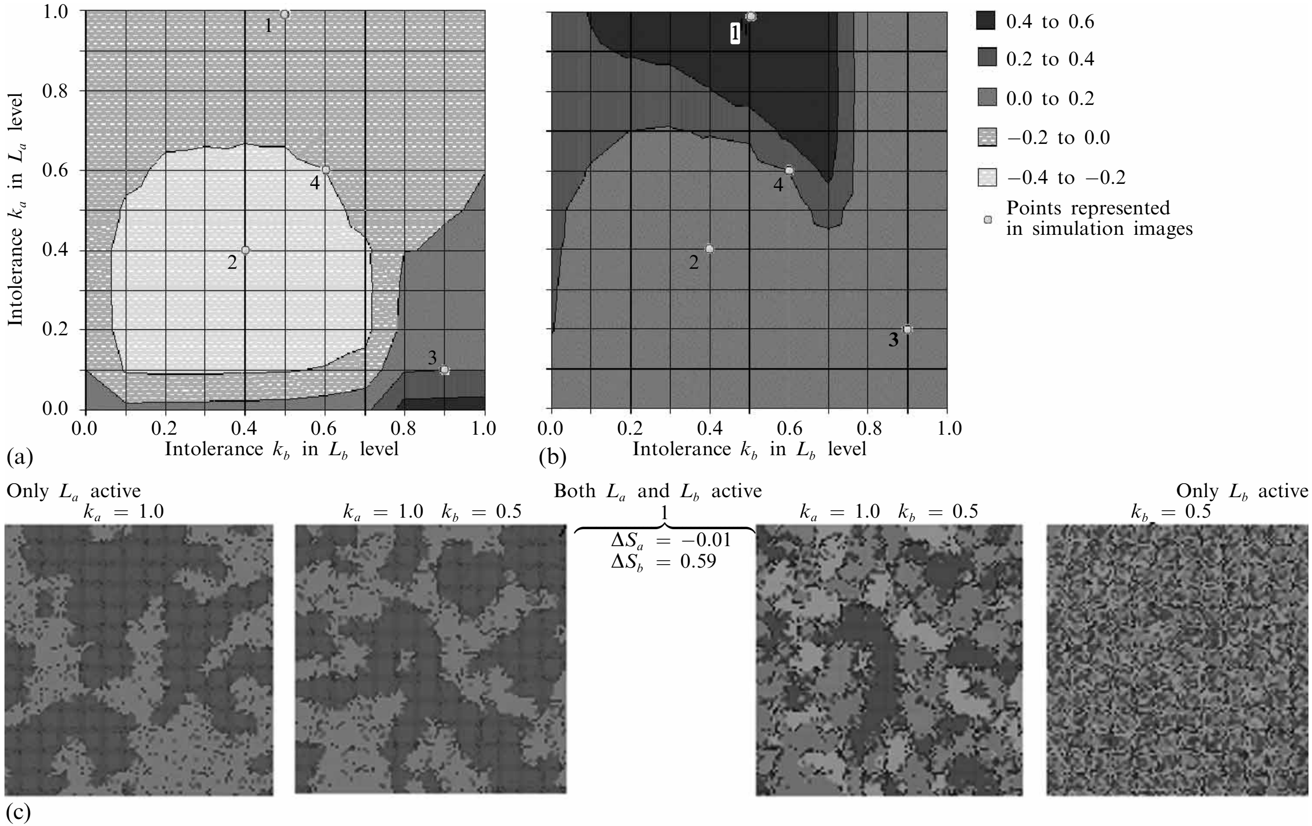
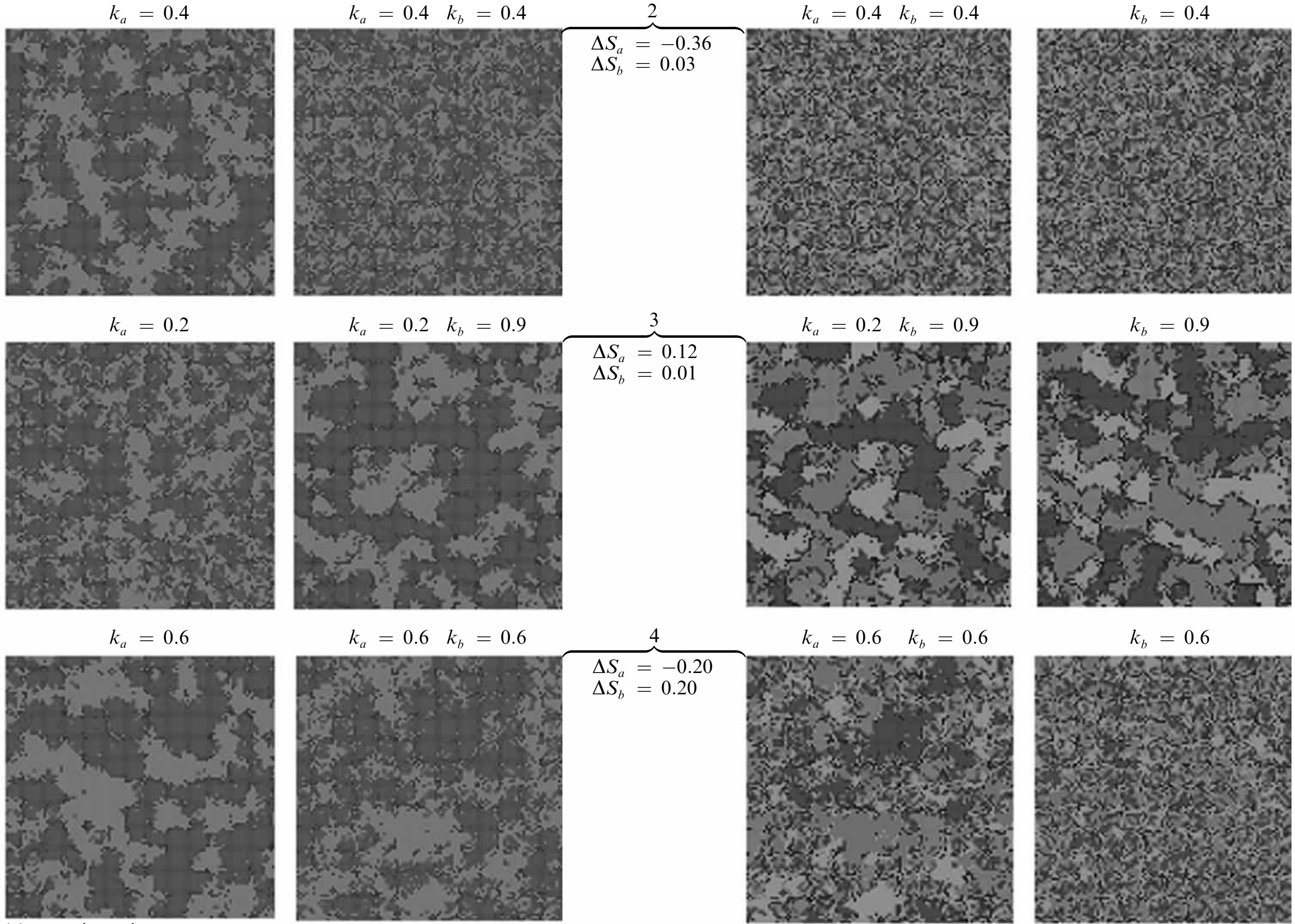


Figure 5. Additional value of segregation (ΔS) contributed by hierarchical levels of ethnic residential distributions for different values of k_a and k_b. (a) The contribution of L_b to segregation at L_a; (b) The contribution of L_a to the segregation at L_b. Points 1–4 represent simulation images (c) at selected values of parameter k (intolerance) for different qualitative domains of ΔS: (point 1) strong top-down aggregation, (point 2) strong bottom-up disaggregation, (point 3) intermediate top-down and bottom-up aggregation, (point 4) strong top-down aggregation and bottom-up disaggregation. A colour version of this figure can be viewed at http://www.envplan.com/misc/b31156. Each group is represented by one colour: blue or red; each subgroup is represented by a different shape of the group's colour.



(c) continued

Figure 5 (continued).

The results clarify that L_a strengthens segregation in L_b mainly in domains where k_a is relatively high ($k_a > 0.5$) but k_b is not ($k_b < 0.7$). Alternatively, L_b weakens segregation (S_a) in L_a when the degree of intolerance at the two levels is not high ($k_a, k_b < 0.7$). Nonetheless, L_b can, potentially, strengthen segregation at L_a when intolerance at the lower level is very high ($k_b > 0.7$). Hence, the levels of hierarchy can simultaneously strengthen each other in cases of strong intolerance at both levels ($k_a, k_b \sim> 0.7$).

To clarify, the influence of one level on segregation at the other level at different values of k_a and k_b, the contribution to segregation (ΔS) at each level was calculated as the difference between the actual degree of segregation (S) of a given level when both levels are active and the degree of segregation of that level when it alone is active, specifically, $\Delta S_a = S_a k_{b>0} - S_a k_{b=0}$ and $\Delta S_b = S_b k_{a>0} - S_b k_{a=0}$. The results of this calculation and simulation images of the contribution of the different values of ΔS_a and ΔS_b are displayed in figure 5. Three qualitative domains appear as a result of the influences described above, depending on the different values of parameter k (see figure 5).

Domain A ($k_a > 0.5$, $k_b < 0.7$): The influence of the top-down aggregation effect is strong (a strong positive contribution of L_a to segregation at L_b), whereas the influence of the bottom-up disaggregation effect is weak (a weak negative contribution of L_b to segregation at L_a). This influence is illustrated in figure 5(c) (point 1) by a series of simulation images of the residential patterns obtained at both levels with the maximal top-down aggregation effect. Hence, point 1 is the focal point of domain A; the relative increase of segregation at the lower level (ΔS_b) equals 0.59 whereas the upper level, ΔS_a equals only -0.01.

Domain B ($k_a < 0.7$, $k_b < 0.7$): The influence of the bottom-up disaggregation effect is strong (a strong negative contribution of L_b to the segregation at L_a), whereas the influence of the top-down aggregation effect is weak (a weak positive contribution of L_a to the segregation at L_b). The simulation images presented in figure 5 (point 2) demonstrate the focal point of this domain; the decrease in segregation at level L_a is $\Delta S_a = -0.36$ whereas the positive contribution at level L_b is $\Delta S_b = 0.03$ only.

Domain C ($k_a, k_b > 0.7$): Each level of the hierarchy simultaneously strengthens the other. However, the bottom-up positive influence is relatively much more powerful because of the strong bottom-up aggregation effect. That effect, as discussed in section 3.1, characterizing situations where the degree of intolerance at level L_a is very low, such as that represented by figure 5 (point 3), where $k_a = 0.2$, $k_b = 0.9$. The results in that case are: $\Delta S_a = 0.12$, $\Delta S_b = 0.01$.

The results presented in figure 5 reveal that the reciprocities between levels of ethnic residential distribution can be qualitatively transformed in response to changing intensities of intolerance at both levels. In such a case, the transition between the domains indicated above can be especially unbalancing for the reciprocities between the levels. An example of such a situation is illustrated in figure 5 (point 4), where aggregation and disaggregation effects operate simultaneously at equal intensity. This creates a hybrid reverse effect where the bottom-up influence entails primarily disaggregation whereas the top-down influence entails primarily aggregation. The simulation images presented in figure 5(c) (point 4) are typical examples of reciprocities between levels of ethnic residential distribution: the top-down influence helps overcome constraints while the bottom-up effect intensifies the constraints that the agents face.

The top-down influence consistently strengthens segregation in the residential patterns at the lower level (P_b) because of the *spatial inclusion* observed between the residential patterns found at different levels. Spatial inclusion indicates physical or tangible nesting of the physical regions covered by those patterns. Accordingly, because the residential patterns of P_b are physically fully nested within those of the patterns of P_a, segregation between the lower residential patterns occurs within the space occupied by the upper residential patterns. For example, the segregation between P_b patterns P_{11} and P_{12} occurs within the physical space occupied by P_a pattern P_1. In other words, when the P_a and the P_b spatial patterns act simultaneously, the first channels the second toward a defined physical space and thereby decreases the *packing capacity* constraint that agents face when looking for a suitable location to which to migrate. This enables the bottom level to stimulate segregated residential patterns that, from the perspective of systems theory, can be viewed as efficiently functioning entities because of their hierarchical organization (Coffey, 1981; Simon, 1969, pages 192–229). As illustrated in figure 5 (point 1), the homogeneous clusters at the top level provide optimal conditions for segregation at the bottom level; in effect, this promotes segregation between two instead of four groups. In contrast to the top-down effect, the bottom-up effect decreases the possibility of finding desired locations at the L_a level through the influence of a disaggregation effect. The need to fulfil the agents' preferences for a specific ethnic composition at the lower level *increases* the packing capacity constraint they face, given that imperfect or broken homogeneous clusters emerge at the upper level, as illustrated in figure 5 (point 2).

The differences between top-down and bottom-up effects on the intensity of the packing capacity constraint can be demonstrated by an analysis of migration. I examined two variables: the ratio of agents who tried to migrate, that is, potential migration in a given iteration, and the ratio of agents who failed to do so, that is, they did not find a suitable new location and stayed at their present location despite the high dissonance. The values of these variables (see figure 6) show that bottom-level migration and failed migration rates are relatively much higher than the respective top-level rates as a result of different *levels* of packing capacity constraints. The operation of top-down aggregation can be clearly observed: potential but especially failed migration rates decrease when the respective actions are taken on both levels simultaneously instead of on the bottom level only, that is, a decrease in the gap between preferences for ethnic composition and actual behaviour. For example, when agents act in the context of the bottom level only, at intolerance of 0.5 ($k_a = 0$, $k_b = 0.5$), 12% of the agents do not find a suitable new location (the total migration rate is 22%). But when the agents

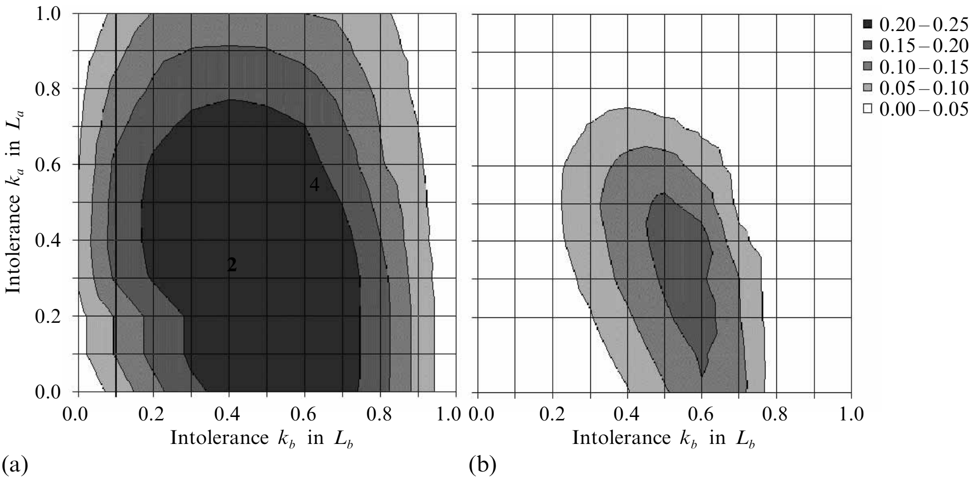


Figure 6. Migration implications of top-down and bottom-up effects: (a) ratio of agents who tried to migrate; (b) failed migration attempts.

also act according to the intolerance at the top level ($k_a = 1.0$, $k_b = 0.5$), just 1% on average do not succeed in finding a new location (from a potential migration rate of 13%).

The migration analysis illustrates how intolerance at the bottom level weakens segregation at the top level, that is, an increase in the gap between preferences for ethnic composition and actual behaviour. In general, no significant amount of failed attempts to find a new location can be identified when agents act solely in response to top-level conditions. But when the agents act according to bottom-level in addition to top-level conditions, the potential and failed migration rates increase. Furthermore, the bottom-up influence is felt mainly when $k_b = 0.2 - 0.7$. This range actually fits the domain where the disaggregation effect is at its maximal intensity (see figures 4 and 5). However, if intolerance at the bottom level is high, that is, $k_b \sim> 0.7$, and agents create segregated patterns at an earlier stage, they face minimal constraints. In that case, the patterns move toward the domain where the hierarchical levels reinforce each other.

In light of these results, it is clear that the consequences of interdependence between levels of ethnic residential distribution can be qualitatively changed in response to the intensity of the agents' intolerance. However, the general phenomenon observed tends to the reverse: the bottom-up influence entails primarily disaggregation between groups at the upper level whereas the top-down influence entails primarily aggregation of the subgroups at the lower level.

The robustness of these relations was investigated from several aspects. I analyzed the influence of the size of the cellular space (50×50 instead of 100×100), of the probability of an agent acting in each iteration (0.5 instead of 1.0) and of the initial distribution of agents, with a distribution over 90% of the cells instead of an empty cellular space. During all these tests, the results did not change significantly.

4 Conclusions

The Schelling model provides a theoretical framework for dealing with the effect of ethnic preferences on residential patterns. In this paper I have investigated the influence of the organization of an agent's ethnic identities on ethnic residential patterns by extending that model to include a further hierarchical level, that is, the agents' ethnic identities are organized in a two-level hierarchy.

ABS reveals that the degree of segregation of residential patterns at a given level of ethnic residential distribution can also be the result of responses to intolerance behaviour at another level. The simulation experiments also show that the consequences of top-down and bottom-up interdependence of ethnic residential distributions can qualitatively change in response to varying intensities of intolerance at both levels (k_a, k_b). However, as a result of the asymmetric nesting of agents' ethnic identities and the tangible residential patterns subsequently established, top-down and bottom-up influences are generally displayed in the following form: intolerance behaviour at the top level strengthens observed segregation at the bottom level, whereas intolerance behaviour at the bottom level weakens the segregation observed at the top level. Based on these findings, we can conclude that increasing intolerance between the members of ethnic minorities and members of the majority in a city tends to strengthen segregation between the subgroups within the minority ethnic population. Viewed from a positive stance, greater tolerance between minorities and the majority tends to weaken subethnic enclaves in the city. Moreover, tendencies toward self-segregation among some subgroups within an ethnic minority contribute to the moderation of residential segregation between that minority group and the majority.

This conclusion enables interpretation of empirical findings concerning the relationship between the patterns observed at the different hierarchic levels of a given ethnic residential distribution. The case of Yaffo's Arab community, for example, as described in the introduction, can be understood better in light of this conclusion. The evidence of declines in the degree of residential segregation between Christians and Moslems within the Arab community, identified in an earlier stage, may contribute to the decreasing contemporary residential segregation between the Arab minority considered as a single group and the Jewish majority. Thus, extending the Schelling model to include an additional hierarchical level opens the door to further research dealing with the role of ethnic preferences on residential choice. Such research would enable evaluation of the consequences of individual preferences for the ethnic composition of residential patterns irrespective of the hierarchic level of ethnic residential distribution being discussed.

Moreover, the conclusions of this study indicate that the discrepancy between preferences for ethnic composition and residential patterns, a phenomenon already revealed by the Schelling model, not only results from actions taken at one level of the residential hierarchy, it also results from actions taken at other levels. Considered from a wider perspective, urban residential patterns exhibit some autonomy and are not merely the direct consequences of the intolerance felt between members of specific ethnic groups. As such, they can potentially influence institutionalized preferences for specific ethnic compositions.

The experimental findings brought forth in this study invite further questions worthy of research. On the one hand, more empirical evidence is required to support the conclusions drawn from the study. On the other hand, additional experiments are needed with more realistic assumptions related to organization of an agent's ethnic identities, such as asymmetric intolerance between groups and between subgroups. Also needed is research into situations where subgroups are not properly nested within the higher level groups.

References

Barth F, 1969 *Ethnic Groups and Boundaries* (Little Brown, Boston, MA)

Ben Artzi Y, 1980, "The creation of the residential pattern and residential mobility characteristics of the Arabs in Haifa", Jewish – Arab Center, Haifa University, Haifa (in Hebrew)

Benenson I, 1998, "Multi-agent simulations of residential dynamics in the city" *Computers, Environment and Urban Systems* **22** 25 – 42

Benenson I, Torrens P M, 2004 *Geosimulation: Automata-based Modeling of Urban Phenomena* (John Wiley, Chichester, Sussex)

Benenson I, Aronovich S, Noam S, 2005, "Let's talk objects: generic methodology for urban high-resolution simulation" *Computers, Environment and Urban Systems* **29** 425 – 453

Charles C Z, 2000, "Neighborhood racial composition preferences: evidence from a multiethnic metropolis" *Social problems* **47** 379 – 407

Clark W A V, 1991, "Residential preferences and neighborhood racial segregation: a test of the Schelling segregation model" *Demography* **28**(1) 1 – 19

Clark W A V, 2002, "Ethnic preferences and ethnic perceptions in multi-ethnic settings" *Urban Geography* **23** 237 – 256

Coffey W J, 1981 *Geography; Towards a General Spatial Systems Approach* (Methuen, London)

Daley P A, 1998, "Black Africans in Great Britain: spatial concentration and segregation" *Urban Studies* **35** 1703 – 1724

Epstein J M, Axtell R, 1996 *Growing Artificial Societies: Social Science from the Bottom Up* (MIT Press, Cambridge, MA)

Fainstein N, 1996, "Race, class, and segregation: discourses about African Americans", in *Readings in Urban Theory* Eds S Fainstein, S Campbell (Blackwell, Oxford) pp 216 – 245

Farley F, Frey W H, 1994, "Changes in the segregation of whites from blacks during the 1980s: small steps toward a more integrated society" *American Sociological Review* **59**(1) 23 – 45

Flache A, Hegselman R, 2001, "Do irregular grids make a difference? Relaxing the spatial regularity assumption in cellular models of social dynamics" *Journal of Artificial Societies and Social Simulation* **4** http://www.soc.surrey.ac.uk/JASSS/4/4/6.html
Galster G C, 1988, "Residential segregation in American cities: a contrary review" *Population Research and Policy Review* **7**(3) 93 – 112
Gilbert N S, Troitzsch K G, 1999 *Simulation for the Social Scientist* (Open University Press, Buckingham)
Hägerstrand T, 1970, "What about people in regional science?" *Papers and Proceedings of the Regional Science Association* **24** 7 – 24
Handelman D, 1977, 'The organization of ethnicity" *Ethnic Groups* **1** 187 – 200
Hegselmann R, Flache A, 1998, "Understanding complex social dynamics: a plea for cellular automata based modeling" *Journal of Artificial Societies and Social Simulation* **1** http://www.soc.surrey.ac.uk/JASSS/1/3/1.html
Krysan M, Farley R, 2002, "The residential preferences of blacks: do they explain persistent segregation?" *Social Forces* **80** 937 – 980
Laurie A J, Jaggi N K, 2003, "Role of 'vision' in neighborhood racial segregation: a variant of the Schelling segregation model" *Urban Studies* **40** 2687 – 2704
Massey D S, Denton N A, 1989, "Hypersegregation in US metropolitan areas: black and Hispanic segregation along five dimensions" *Demography* **26** 373 – 391
Omer I, 2003, "The Jewish-Arab residential distribution in Yaffo, 1961 – 1995" *Merhavim—Studies in the Geography of Israel and the Middle East* 3 (in Hebrew), Tel Aviv University, Tel Aviv
Parkes D, Thrift N, 1980 *Times, Spaces and Places: A Chronogeographic Perspective* (John Wiley, New York)
Peach C, 1996, "Good segregation, bad segregation" *Planning Perspectives* **11** 379 – 398
Peach C, 1998, "South Asian and Caribbean ethnic minority housing choice in Britain" *Urban Studies* **35** 1657 – 1680
Portugali J, 2000 *Self-organization and the City* (Springer, Berlin)
Portugali J, Benenson I, Omer I, 1997, "Spatial cognitive dissonance and sociospatial emergence in a self-organizing city" *Environment and Planning B: Planning and Design* **24** 263 – 285
Robinson V, 1986 *Transients, Settlers and Refugees: Asians in Britain* (Clarendon Press, Oxford)
Sakoda J M, 1971, "The checkerboard model of social interaction" *Journal of Mathematical Sociology* **1** 119 – 132
Schelling T, 1971, "Dynamic models of segregation" *Journal of Mathematical Sociology* **1** 143 – 186
Schelling T, 1974, "On the ecology of micro-motives", in *The Corporate Society* Ed. R Marris (Macmillan, London) pp 19 – 55
Simmons I, 1981, "Contrasts in Asian residential segregation", in *Social Interaction and Ethnic Segregation* Eds P Jackson, S J Smith (Academic Press, London) pp 81 – 100
Simon H A, 1969 *The Sciences of the Artificial* (MIT Press, Cambridge, MA)
Smith B, 1996, "Mereotopology: a theory of parts and boundaries" *Data and Knowledge* **20** 287 – 304
van Lierop W F J, 1986 *Spatial Interaction Modeling and Residential Choice Analysis* (Gower, Brookfield, VT)
Wasserman H, Yohe G, 2001, "Segregation and the provision of spatiality defined local public goods" *The American Economist* **45** 13 – 24
Zubrinsky C L, Bobo L, 1996, "Prismatic metropolis: race and residential segregation in the city of the angels" *Social Science Research* **25** 335 – 374