Residential Distribution in the City – Reexamined

Itzhak Benenson, Ehud Or, Erez Hatna, Itzhak Omer
Department of Geography and Human Environment, Tel-Aviv University
Tel-Aviv, Israel
bennya@post.tau.ac.il

SUMMARY
The recent boom in high-resolution GIS makes possible the investigation of urban residential distributions at the resolution of individual buildings and families. Availability of these data has inspired reexamination of the Schelling model of residential segregation and its application for simulating population patterns in real cities. The current paper argues that the Schelling model satisfies this criterion and consequently applies it to explain real-world residential pattern dynamic in nine Israeli cities. The study is based on data obtained from a unique Israeli census database in which individual and family records are geo-referenced to the layer of buildings. Analysis of the income-based residential patterns reveals their high heterogeneity – a mix of homo- and heterogeneous areas is typical for eight of the nine cities investigated. We explain this heterogeneity by the presence of a low fraction of wealthier householders who are highly tolerant of their poorer neighbors and can thus reside in their proximity. Extension of the model in this direction results in a qualitative correspondence between the model's outcomes and the residential patterns observed in Israeli cities.

KEYWORDS: *Agent-Based modeling, Residential distribution, Population census,*

LOCAL INTERACTIONS – DO THEY DETERMINE URBAN RESIDENTIAL PATTERN?

Population groups tend to segregate and sociological theory supports this view with the classic Schelling model of residential segregation considers individual agents, who care about the composition of their local neighborhood only. Basically, the model, proposed independently by Thomas Schelling (Schelling 1969) and James Sakoda (Sakoda 1971) considers social agent belonging to one of two mutually avoiding types – b and w, and relocating in reaction to the fraction of the agents of their own and of the strange types among the neighbors.

To remind, the outcome of the Schelling model depends on the threshold fraction of strangers $\mathbf{S_{Th}}$ the agent **cannot** tolerate, and on the initial population density. In case of characteristic of the city high population density, low sensitivity of the agents, say $\mathbf{S_{Th}}$ ~ 80% and above, does not force agents to move and the residential pattern is preserved in time after short period of minor changes. The value of $\mathbf{S_{Th}}$ between ~80% and ~20% results in segregated city (agents leave the neighborhoods with the high fraction of strangers and reside among friends), while high sensitivity to the strangers, $\mathbf{S_{Th}}$ ~ 20% and below, results in unrealistic situation, when most of agents change their location each time step.

Recent theoretical research reveals qualitative and robust character of the Schelling basic result. Namely, if the tendency to stay within those who are similar to you is not too weak, then the residential distribution in the city converges to segregation. The statement remains true for various definitions of the neighborhood, rules of relocation, irregular partition of space, etc. (Portugali and Benenson 1994; Portugali and Benenson 1995; Portugali and Benenson 1997; Benenson 1998; Benenson 1999). Recent experimental results confirm Schelling model outcome for the situation of the ethnic group competing for space (Benenson, Omer et al. 2002; Bruch and Mare 2004).

The Schelling model has its inherent shortcoming: it does not account for the economic factors. As far as we depart from the extremes of the self-segregating minorities, as foreign Muslims workers in West European countries, underpaid, deeply religious and having weak command of the local language, the view of the local attraction/avoidance as the determinant of the residential pattern becomes questionable.

The economic view of the residential distribution focuses on the housing prices, and assumes that the residential distribution is a "fast variable," which adjusts itself to the slower changing distribution of price. The Hedonic Price Model (Rosen 1974) expresses the property value as a linear or nonlinear regression on the numerous property's and environmental attributes - physical size, floor, number of rooms, age, traffic noise level of pollution, location, accessibility, and so forth (Wilhelmsson 2000; Irwin 2002), at all levels of resolution. The advantage of the Hedonic model is in its basis on the measurable factors, the disadvantage is in its static character.

Can we combine the simple scheme of the Schelling model with the view of economic relationships as determining householder's residential decisions? Is it possible to experimentally investigate whether the distribution of the households by income is governed by local interactions? Until recently, the answer was "not," just because existing aggregate data on urban residential distribution are insufficient for that. In Israel, for example, the smallest unit used for demographic and socio-economic examinations - statistical area – contains at average 3000 residents. The study of local factors, involved in explanations of the different models of the residential distribution, demands examination at resolution of a single household or, at least, a single building.

During the last decade the situation has changed and quantitative characterization of urban social phenomena is no more limited to the units of the aggregate partitions (Benenson and Omer 2003). In Israel, this situation is especially favorable - beginning from the population census of 1995, every individual is geo-referenced regarding the house he/she occupies.

In this paper, we explore these high-resolution census data on nine Israeli cities. The data are obtained from the Israeli Central Bureau of Statistics (ICBS), and investigated under the supervision of the ICBS stuff. The goal of our research is to present a high-resolution view of the residential distribution in the city and to understand at what extend we can follow Schelling or other models in explaining it.

RESIDENTIAL DISTRIBUTION IN ISRAELI CITIES AT HIGH RESOLUTION

The database

The investigated dataset consists of interrelated spatial and non-spatial components. Census GIS contains layers of roads (with two important attributes representing road width and road type), open areas (mostly parks) and, most important, the layer of building foundations. Two main census non-spatial tables are that of personal data – age, origin, place of studies/work, etc., and that of the data on householder and household – ownership of apartment, number of cars, TV, etc. These two tables are related – each personal record contains the identifier of the family, while the table of the households is related to the GIS layer of houses – each family record contains identifier of a building the family is located at a moment of a census. The ICBS database is the product of the population census of 1995.

Critical for our study, after the census was completed, the census personal records were related to the personal records of the Israeli Ministry of the social security, the latter containing data on all sources of the annual income of the family members - salary, income of self-employed persons and social security payments. We did not attempt to estimate non-reported income, and accepted non-scientific faith that social security data on personal income in Israel do reflect family economic reality.

To confront the models with the residential reality, we examined the distributions of four householders' characteristics – income, number of children (both available for 100% of the individual), and education and the year of buildings construction, available for 20% of the individual (the extended questionnaire). The building-family and family-individual relationships supported in the database make it possible to construct residential distributions at a resolution of separate buildings.

Investigated cities

The analysis we present here is based on census data on nine cities in the central part of Israel. Tel-Aviv, with some 350,000 residents, is the largest of those cities while the populations of the others vary between 150,000 (Natanya) and 30,000 (Rosh Haayin). For nine cities selected (the full list is found in Table 1), we constructed maps of family income, mean level of education and fraction of children at the resolution of buildings.

For the convenience of numeric analysis, we have transformed the data on personal monthly income into logarithms by the basis of 2, which makes distribution of the personal income much closer to the normal and better fits to human understanding of the "more rich or poor." Indeed, don't we think of somebody as earning two times more than the other, and not as earning 1000$ more?

Table 1: Cities investigated

City	Bat Yam [1]	Ashdod [2]	Lod [3]	Tel-Aviv [1]	Ramla [3]	Natanya [1]	Rosh Haayin [2]	Kfar Saba [1]	Ramat Hasharon [1]
Pop (thds)	140.0	130.0	52.0	350.0	40.0	150.0	40.0	70.0	40.0
Area (km^2)	8.0	44.3	9.0	51.3	9.9	29.0	24.6	14.2	16.8
Populated Buildings	2488	2881	1828	17101	2423	5413	3025	3244	3146
Households (thds)	46.0	36.5	13.6	144.0	16.1	47.1	8.0	21.6	11.9

[1]Founded in the first half of the XX century, before the establishment of Israeli state
[2]Founded soon after establishment of Israeli state in 1948
[3]Ancient Arab cities, occupied during the war of independence of 1948

Characterization of the residential pattern and its presentation as a map

We are interested in characterizing local structure of the residential pattern, just because our starting point – Schelling model – is based on the neighborhood relationships. In what follows, we do that on the base on the Voronoi coverage, which is constructed on the base of the buildings' centroids. Two building are considered as neighbors if three conditions hold simultaneously (Figure 1a):

- Buildings' Voronoi polygons have common edge
- The distance between the buildings' centroids is below 150 m
- The line connecting centroids of the buildings does not cross a major road (the road with two or more lanes in each direction)

The intuitive meaning of this definition is evident – two buildings are neighbors if they are not too far (second condition), each of them could be seen form the other (first condition) and they are not separated by the main road (third condition). This definition makes possible recurrent definition of the neighborhoods of higher orders. Neighborhood $U_1(H)$ of the first order of a house H consists of

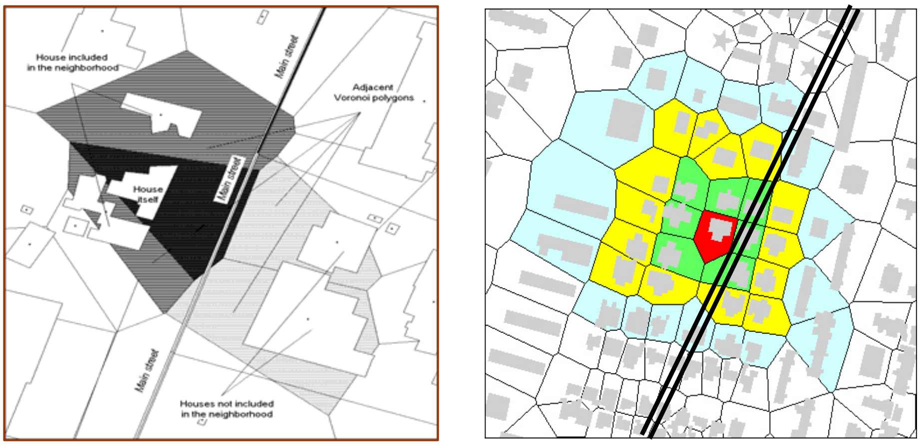
its immediate neighbors. Neighborhood $U_2(H)$ of the 2nd order consists of a $U_1(H)$ and neighbors of the houses included into $U_1(H)$, etc (Figure 1b).
We characterize the local structure of urban residential patterns in the simplest possible way by means moving average $m_{H,Ui(H)}$ and moving standard deviation $s_{H,Ui(H)}$ over the neighborhoods of the given order i:

$$m_{H,Ui(H)} = \Sigma_{G\in Ui(H)} z_G / \mathbf{N}_{G\in Ui(H)} \quad (1)$$

$$s_{H,Ui(H)} = \sqrt{(\Sigma_{G\in Ui(H)}(z_G - m_{H,Ui(H)})^2/(\mathbf{N}_{G\in Ui(H)}-1))} \quad (2)$$

where z_H is a value of the characteristic of a house H, $U_i(H)$ denotes H's neighborhood of i-th order, and $\mathbf{N}_{G\in Ui(H)} = \Sigma_{G\in Ui(H)}1$ is a number of elements in a neighborhood $U_i(H)$.

More complex indices, as Local Indices of Spatial Association (LISA) of Geary, Getis and Moran (Omer and Benenson 2002) provided the same results.



a b

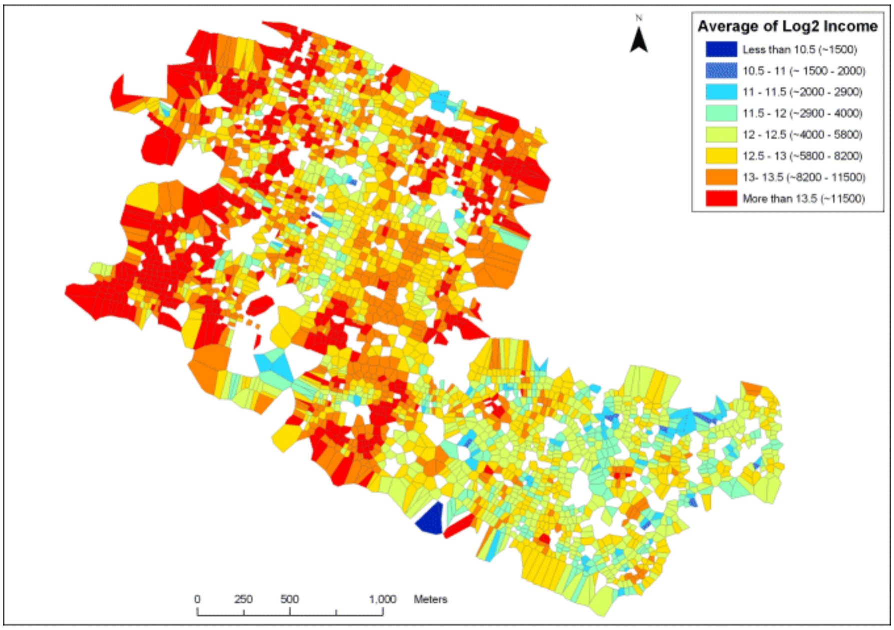
Figure 1: (a) Definition of the neighborhood; (b) Neighborhoods of order 1 (marked green), 2 (marked yellow) and 3 (marked cyan light)

RESULTS

Residential patterns by income in the Israeli cities

Figure 2 presents residential distribution by income in Ramat-Hasharon, which is the most heterogeneous among the nine investigated cities, Figure 3 presents the most homogeneous residential pattern, observed in Bat Yam and Figure 4 presents the intermediate situation – a mix of homo- and heterogeneous areas that is typical for Tel-Aviv and most of the cities we investigated:

a



b

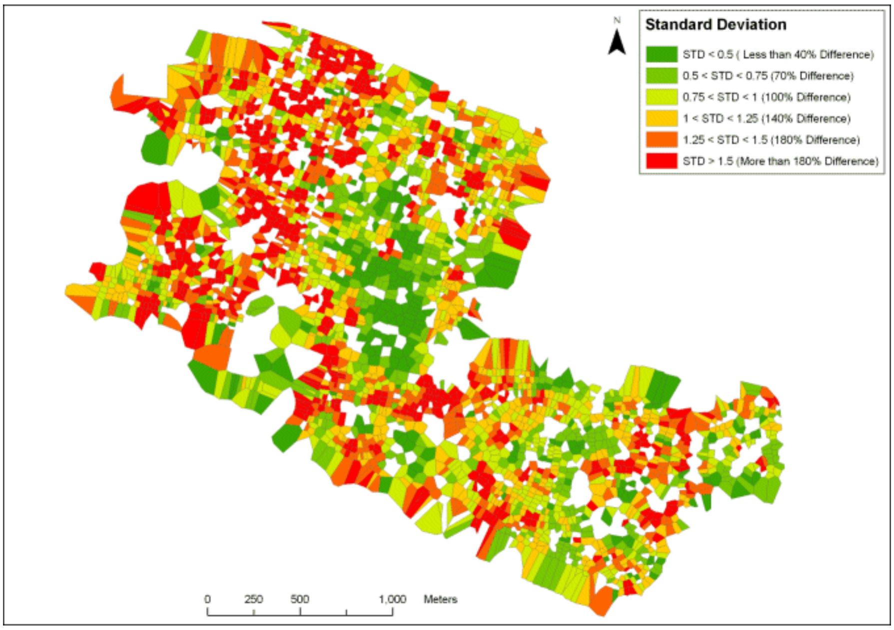
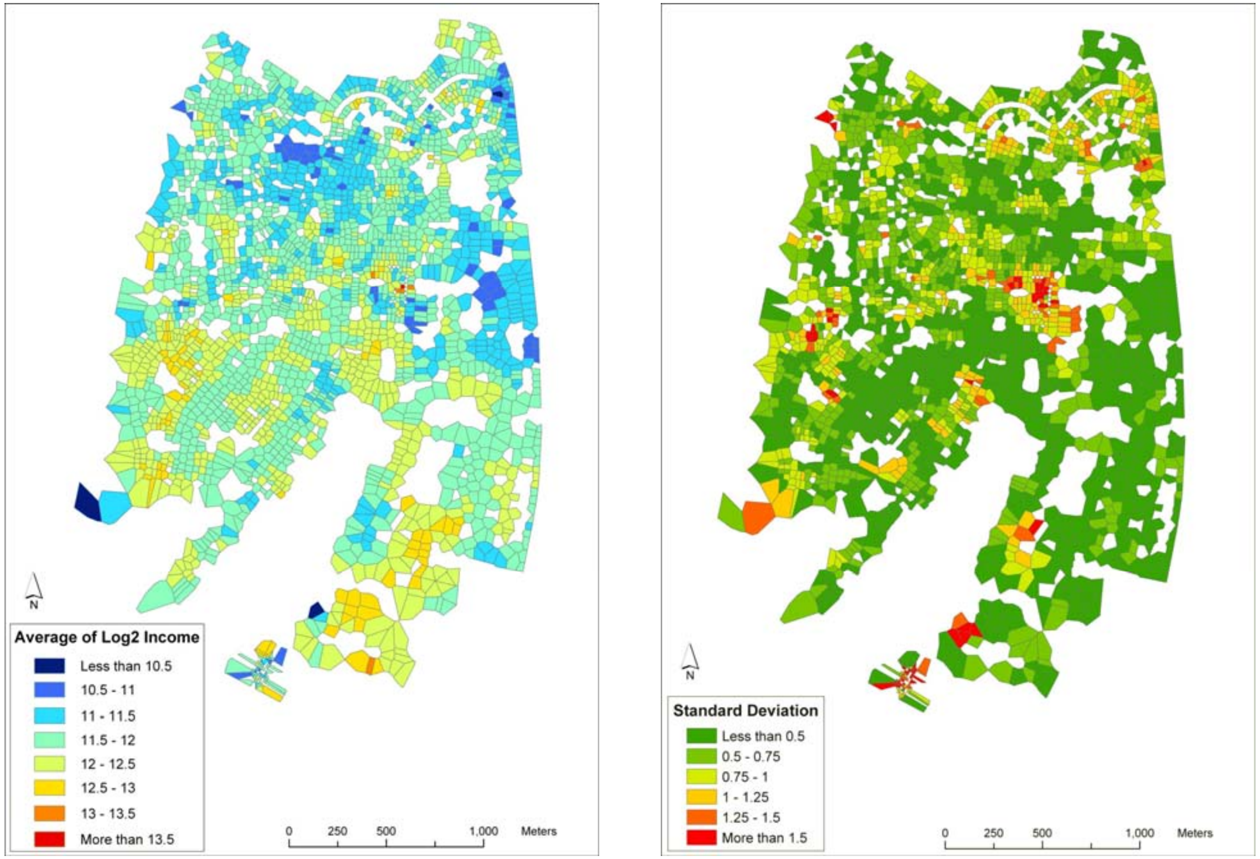
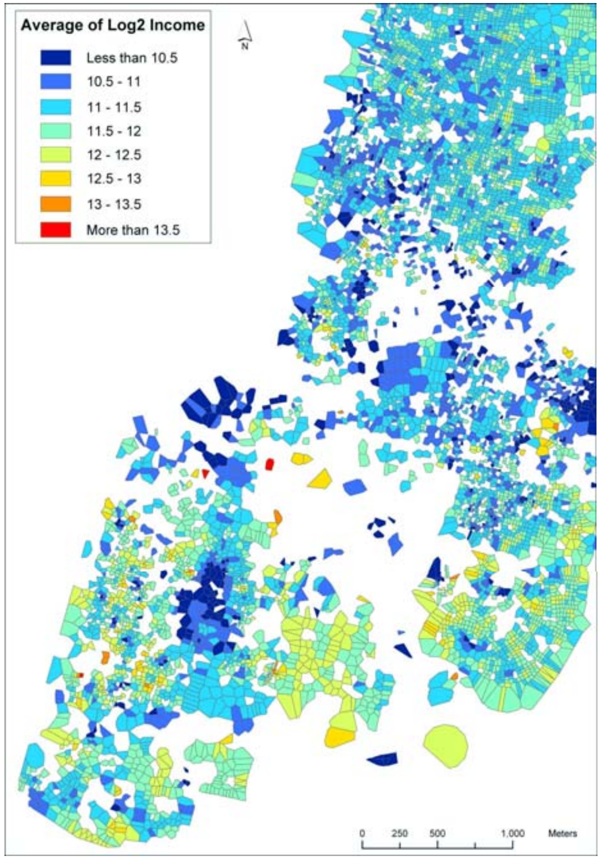


Figure 2: The maps of average (a) and STD (b) of Log_2(Income) over the neighborhoods of the 1st order for Ramat-Hasharon, the most heterogeneous of nine cities investigated.

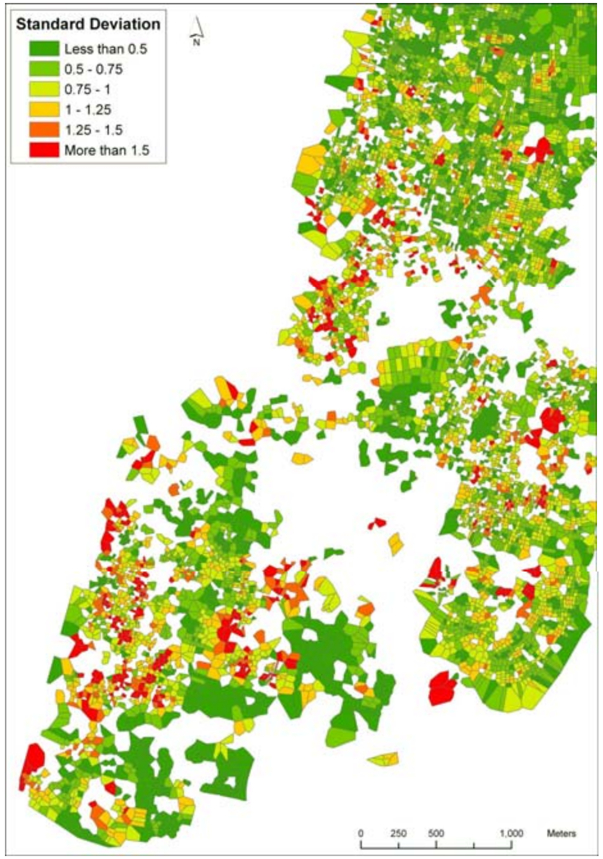


a b

Figure 3: Distributions of averaged neighborhood income and income STD in Bat-Yam, the most homogeneous of the nine cities investigated



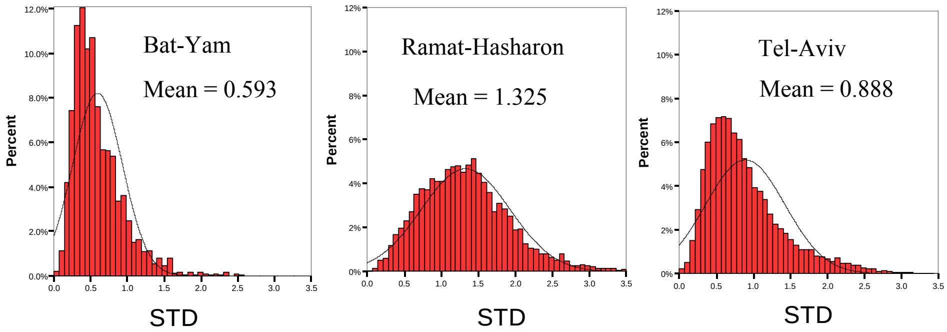
a



b

Figure 4: Distributions of average neighborhood income and income STD in the southern part of Tel-Aviv, which displays a mix of homo- and heterogeneous areas

Figure 5 presents distribution of the STD in these cities



a b c

Figure 5: Distribution of income STD over neighborhoods in Ramat-Hasharon, Bat-Yam and Tel-Aviv (residential patterns are presented in Figures 2, 3, 4 above)

The distribution of local STD for Bat Yam (Figure 5a) confirms to the visual impression from the map (Figure 3b) and Bat Yam income spatial pattern (Figure 3a) perfectly fits to the Schelling model in its continuous version (Benenson 1999), presenting smooth distribution, with clear peaks and valleys. The opposite situation is characteristic of Ramat Hasharon (Figure 2), where most of the area is highly heterogeneous, as is confirmed by the distribution of the local STD (Figure 5b). Tel-Aviv (Figure 4, Figure 5c) presents an intermediate example. Generally, the situation in Israeli cities is closer to that of Ramat Hasharon than of Bat Yam (Table 2):

Table 2: Mean Income and STD over the neighborhoods in nine investigated cities

City	Mean Income	Mean STD
Bat-Yam	11.773	0.593
Ashdod	10.574	0.804
Lod	12.184	0.876
Tel-Aviv	11.605	0.888
Ramla	12.059	0.923
Natanya	11.870	0.941
Kfar-Saba	12.300	1.075
Roah-Haayin	12.640	1.047
Ramat-Hasharon	12.555	1.325

The important consequence of the heterogeneity is that the wealthy-looking dwellings in low-income neighborhoods are not occasional, but typical – areas heterogeneous according to the income of the households there cover significant portions of nine Israeli cities investigated. Wealthy people remain in the neighborhoods together with those, whose income is essentially lower, despite the fact that they could afford another location and high population mobility in Israel (5% annual rate of internal migration in Israel at average).

AN EXPLANATION OF THE HETEROGENEITY

Possible influence of the infrastructure factors

Essentially cheaper but yet high-level housing are the foremost reasons that can influence wealthy people's decision to reside in the neighborhoods with essential fraction of the poor population and stay there for a long time. The everyday life in such neighborhoods is also cheaper, while the conditions for bringing up and educate children are usually worse that in the wealthy and homogeneous areas.

We were not able to validate these relationships directly, and did that indirectly, by examining correlation between average income and three characteristics of a building and building population, we could obtain – building age, the fraction of the householders graduated from the high school and the fraction of children under 16 years old. We base here on several assumptions: First, in Israeli cities, newer dwellings are usually more expensive than the neighboring ones. Second, more educated can be more tolerant to the neighbors and, thus, more inclined to exploit advantages of heterogeneous neighborhoods. Third, younger wealthy families with children might avoid residing in poorer areas, where the level of the education system is usually lower.

Shortly, the correlation between the income and building age are below 0.3 in five of seven cities of sufficient number of observations; it is about 0.5 in Tel-Aviv (N = 117) and Kfar-Saba (N = 98). The correlation between the income and the level of education always remains positive, between 0.2 and 0.4, the correlation between the income and fraction of children fluctuates around zero. The overall value of R^2 always remains below 0.3.

The above correlations are "typical" for the published hedonic regressions that are based either on samples of the householders or on the aggregate data, and relate characteristics of the householders to characteristics of the infrastructure, which seldom provide goodness of fit above 30% (Benenson 2004). We, thus, decided that in our case the infrastructure and non-personal social factors explain small part of the heterogeneity; the majority of Israeli cities are, thus, over-heterogeneous. This view contradicts to Schelling-inspired view of urban reality. Attempting to explain the phenomenon of over-heterogeneity, we applied to the personal characteristics of the householders.

The personal tolerance hypothesis

Our hypothesis is that wealthy householders keep residing in poor region because their *personal tolerance to the neighbors* is high**.**

In the Schelling model, all agents react to the neighbors in the same manner. Is this assumption valid in the real city? Could householders differ according to their tolerance? To answer this question, we applied to the "most convenient" population group - wealthy householders, chosen those who reside in the heterogeneous neighborhoods and simply asked about their attitude to the neighbors. For control, we applied to the wealthy householders residing in the homogeneous neighborhoods. As above, we distinguish between two kinds of the neighborhoods based on the local averages and STD over the 3rd and 1st neighborhoods (Figure 6).

Within heterogeneous neighborhoods, we applied to the households "looking wealthy" and asked the householder "whether you consider yourself as a wealthy person?" If an answer to this preliminary question was positive, we continue asking her/him about the attitude to the neighbors. In wealthy homogeneous neighborhoods, all households "looked wealthy" and we selected householders randomly. Four heterogeneous and three homogeneous neighborhoods were selected, and there was no control over the number of recipient in each neighborhood.

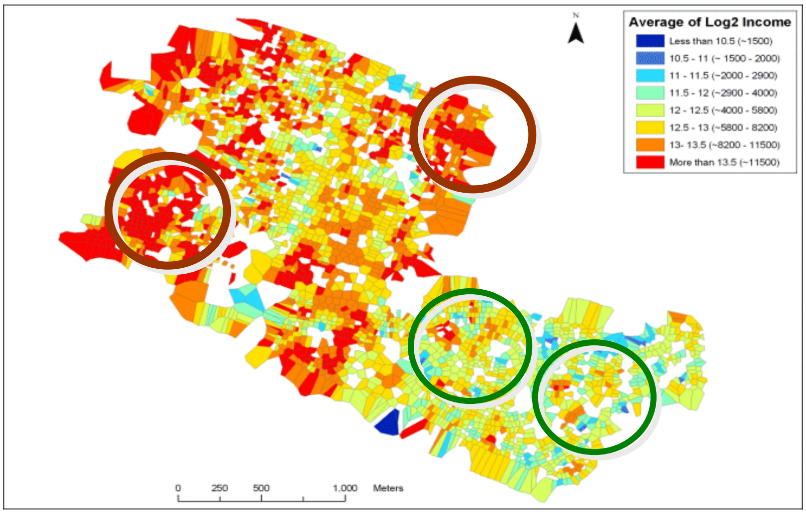


Figure 6: Selection of the questionnaire recipients according to the high-resolution map of income STD: wealthy living among the wealthy (brown circles) and wealthy living among the poor (green circles)

A one-page questionnaire the householders answered contained six questions of the same kind “Is it important for you that [characteristic X] among your neighbors in [your house/neighboring houses] is the same as yours?” [Characteristic X] was “socio-economic status,” “culture,” or “education,” and the recipients had to score their attitude according to the 5-grade scale, with 1 as the lowest and 5 as the highest grades. Let us note that part of the households were one-family houses; the question about householders’ attitude to the neighbors in their house is thus valid for the part of the recipients only

The means of the individual estimates are presented in Table 3 As can be seen, wealthy people in heterogeneous areas are indeed essentially more tolerant of their poorer neighbors, especially if to those residing in adjacent houses. The correlation between the tolerance to the neighbors in the house and tolerance to the neighbors in the neighboring houses is about 0.9 in all six cases.

Table 3: Mean grade of the answer to a question: Is it important for you that [**characteristic X**] among your neighbors in [**your house/neighboring houses**] is the same as yours?

Characteristic X	In your house		In the neighboring houses	
	Rich among poor (n = 18)	Rich among rich (n = 13)	Rich among poor (n = 20)	Rich among rich (n = 20)
Socio-economic status	2.56	3.31	2.20	3.10
Cultural level	2.72	4.00	2.35	3.75
Level of education	2.21	3.38	1.80	3.10

Let us note that talking to the surveyors, wealthy people residing in heterogeneous areas have pointed to many advantages of their place - economic, architectural, locational, etc; however, different householders pointed to different advantages.
Our sample is too small to make decisive conclusions. In the same time, it is sufficient to reexamine Schelling model by assuming that the reaction to the strangers is *agent-specific*. Indeed, varying level of tolerance provides an easy explanation of the observed over-heterogeneity – heterogeneous areas persist because tolerant and wealthy householders keep residing there; wealthy intolerant householders tend to concentrate within the homogeneous areas. Let us build Schelling-like model for investigating this idea.

RESIDENTIAL DISTRIBUTION IN THE CITY OF HOUSEHOLDERS DIFFERENT IN THEIR TOLERANCE TO THE STRANGE NEIGHBORS – THE MODEL

The idea of the model is as follows: *The residential pattern of the city of intolerant residential agents defines minimal level of urban heterogeneity. Wealthy agents, residing in essentially poorer neighborhoods, turn up the process, thus preserving urban residential heterogeneity.*

The above idea demands a ‘background’ model of urban residential dynamics in the city of householders who differ in their economic abilities. We build this model in a phenomenological way, attempting to be as close as possible to the logics of Israeli residential market. In the model, we consider the growing city and assume that the price of the new dwellings increases with an increase in the economic status of agents residing in the neighboring houses. Each time-step (one month), based on characteristics of the house and the neighborhood, each householder agent estimates the satisfaction of its dwelling and decides whether to stay or to relocate. If the decision is to relocate, an agent searches the opportunities that the city presents, and, if finds sufficiently good ones, attempts to move to the best of them. That is, we employ Take-The-Best algorithm of residential choice (Gigerenzer and Goldstein 1996).
The incentives of the model householder for residing in poorer neighborhood follow the line of Israeli real estate agents promoting dwellings within the poor neighborhoods: buy this cheap house, invest into upgrading, and get the property you could not dream for this money. This incentive is balanced by the tendency to avoid poor neighbors. To formalize the influence of two opposite forces, we split dwelling’s satisfaction into two components – one determined by the agent’s direct reaction to the neighbors, and one determined by agents reaction to the dwelling’s price, and in this respect the model framework extends that of (Portugali, Benenson et al. 1997). The model, which will be presented at the conference in full details, demonstrates that the varying tolerance to the poor neighbors can result in mixed heterogeneous – homogeneous residential distribution, and the result is robust to the lack of knowledge regarding the distribution of the new characteristic – individual tolerance – of the urban householders.

REFERENCES

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

Benenson, I. (1999). "Modeling population dynamics in the city: from a regional to a multi-agent approach." Discrete Dynamics in Nature and Society **3**(2-3): 149-170.

Benenson, I. (2004). Agent-Based Modeling: From Individual Residential Choice to Urban Residential Dynamics. Spatially Integrated Social Science: Examples in Best Practice. M. F. Goodchild and D. G. Janelle. Oxford, Oxford University Press**:** 67-95.

Benenson, I. and I. Omer (2003). "High-resolution Census data: a simple way to make them useful." Data Science Journal (Spatial Data Usability Special Section) **2**(26): 117-127.
Benenson, I., I. Omer and E. Hatna (2002). "Entity-based modeling of urban residential dynamics - the case of Yaffo, Tel-Aviv." Environment and Planning B. **29**: 491-512.
Bruch, E. E. and R. D. Mare (2004). Neighborhood Choice and Neighborhood Change. Los Angeles, Department of Sociology and California Center for Population Research University of California — Los Angeles**:** 78.
Gigerenzer, G. and D. G. Goldstein (1996). "Reasoning the Fast and Frugal Way: Models of Bounded Rationality." Psychological Review **103**(4): 650-669.
Irwin, E. G. (2002). "The effects of open space on residential property values." Land Economics **78**(4): 465-480.
Omer, I. and I. Benenson (2002). "GIS as a Tool for Studying Urban Fine-Scale Segregation." Geography Research Forum.
Portugali, J. and I. Benenson (1994). Competing order parameters in a self-organizing city,. Managing and marketing of urban development and urban life. G. O. Braun. Berlin, Dietrich Reimer**:** 669-681.
Portugali, J. and I. Benenson (1995). "Artificial planning experience by means of a heuristic sell-space model: simulating international migration in the urban process." Environment and Planning B **27**: 1647-1665.
Portugali, J. and I. Benenson (1997). Human agents between local and global forces in a self-organizing city. Self-organization of complex structures: from individual to collective dynamics. F. Schweitzer. London, Gordon and Breach**:** 537-546.
Portugali, J., I. Benenson and I. Omer (1997). "Spatial cognitive dissonance and sociospatial emergence in a self-organizing city." Environment and Planning B-Planning & Design **24**(2): 263-285.
Rosen, S. (1974). "Hedonic prices and implicit markets: Product differentiation in pure competition." Journal of Political Economics **82**: 34-55.
Sakoda, J. M. (1971). "The checkerboard model of social interaction." Journal of Mathematical Sociology **1**: 119-132.
Schelling, T. C. (1969). "Models of segregation." American Economic Review **59**(2): 488-493.
Wilhelmsson, M. (2000). "The impact of traffic noise on the values of single-family houses." Journal of Environmental Planning and Management **43**(6): 799-85.