# *Individuals' cultural code and residential self-organization in the city space*

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## *1. Introduction.*

We consider the city as a complex and open system, that exhibits phenomena of self-organization. We further suggest, that as such a system the city has a special characteristic: its elementary components are human individuals which, unlike the elementary units of non-living and most of the living systems, are themselves self-organizing complex systems. Based on this approach, we have developed a series of agent-based models of city residential dynamics - ***City*** model, with which we were able to show the emergence of different forms of cultural and economic segregation, and, most importantly, the emergence of a new socio-cultural group in the city space (Portugali, Benenson, Omer, 1994, 1997, Benenson, Portugali, 1995, Portugali, Benenson, 1994, 1995, 1997). Our previous studies were based on the presentation of the individual agent's properties, namely *economic status* and *cultural identity*, as one-dimensional quantitative variables. In this paper, we call off this oversimplifying suggestion, regarding agent cultural identity and consider the latter as a *multidimensional* and *qualitative* variable. Such a representation implies that each individual agent in the model has its own personal "cultural code" (reminiscence in its nature a genetic code), and that the cultural groups of the city consist of individuals with identical cultural code. This formulation allows us to study the *recurrent process of socio-cultural emergence and elimination* in the city.

## *2. The model.*

The model we present elaborates on our previous ***City*** models. Like them, it consists of two interacting layers - *an infrastructure* submodel, which is an extension of cellular automata and represents the dynamics of the city's physical structure, and a submodel of *free human agents*, which describes the migratory movements of individuals. It differs from past formulation in its definition of the cultural identity of the agents - this is the novel feature we study in this paper.

### 2.1. The infrastructure submodel.

The infrastructure of ***City*** is a square $\mathbf{M \times M}$ lattice of cells which symbolizes houses. Each house $\mathbf{H}_{ij}$ can be either occupied by an individual agent or remain empty. We consider a $\mathbf{5 \times 5}$ square with $\mathbf{H}_{ij}$ in the center as the *neighborhood* $\mathbf{U(H}_{ij}\mathbf{)}$ of house $\mathbf{H}_{ij}$. Houses differ in their *value* $\mathbf{V}_{ij}$. Each time-step the value of the house is determined anew. When an agent $\mathbf{A}$ occupies house $\mathbf{H}_{ij}$, its value $\mathbf{V}_{ij}$ is updated in accordance with $\mathbf{A}$'s economic status $\mathbf{S}_{A}$ (see below) and the average value of the neighboring houses in the following way:

$$V^{t+1}_{ij} = (S^{t}_{A} + (N(U(H_{ij})) - 1) \cdot <V^{t}_{ij}>_{U})/N(U(H_{ij})) \quad (1),$$

where $<V^{t}_{ij}>_{U} = {}_{Skl}\{V^{t}_{kl} \mid H_{kl} \; e \; U(H_{ij}),\ H_{kl} \# H_{ij}\})/(N(U(H_{ij})) - 1)$ is an average of houses' values in $U(H_{ij})$ besides $H_{ij}$, and $N(U(H_{ij}))$ is a number of houses in $U(H_{ij})$.

When a free agent leaves house $\mathbf{H}_{ij}$, and the latter remains unoccupied, the house's value $\mathbf{V}_{ij}$ is decreasing at a constant rate:

$$\mathbf{V}^{t+1} = \mathbf{d} \cdot \mathbf{V}^{t} \qquad \textbf{(2)},$$

where $\mathbf{d} < \mathbf{1}$. Here and below we omit , when possible, indices of location.

## 2.2. The submodel of free human agents.

The individual free human agents of ***City*** have the ability to estimate the state of the city on its two layers and to behave in line with information regarding **individual**, **local** (referring to the characteristics of the neighborhood's and the neighbors' state) and **global** (referring to the state of the whole city) levels of organization in the city. They immigrate into the city, occupy and change residential locations there, and leave the city when the conditions are unsatisfactory. The agents are characterized by two sets of variables, with which we try to reflect the economic and the cultural characteristics of the human individuals in the city.

### 2.2.1. Economic characteristics.

The economic state of agent **A** occupying house **H** is given by **A**'s *economic status* $\mathbf{S}_A$. The dynamics of individual's status is described in a simple logistic way:

$$\mathbf{S}^{t+1}_{A} = (\mathbf{R}_{A} \cdot \mathbf{S}^{t}_{A} \cdot (1 - \mathbf{S}^{t}_{A}) - \mathbf{m} \cdot \mathbf{V}^{t}_{H}) \, / \, \langle \mathbf{V}^{t} \rangle_{city} \qquad \textbf{(3)},$$

where $\mathbf{R}_A$ is an *individual rate of economic growth*, that does not depend on **t**, and $\mathbf{m} \cdot \mathbf{V}^{t}_{H}$ is a "mortgage payment", proportional to a house's value.

*The local economic information* available to individual agent **A**, occupying a house $\mathbf{H}_{ij}$, is given by the economic status of the neighbors and the houses' values in the neighborhood. Formally, the decision of the model individual depends on the difference $\mathbf{SD}_A$ between **A**'s status and the mean of the neighbors' status and the unoccupied neighboring houses' values

$$\mathbf{SD}^{t}_{A} = \mathbf{Abs}(\mathbf{S}^{t}_{A} - \mathbf{P}^{t}_{ij}) \qquad \textbf{(4)},$$

where $\mathbf{P}^{t}_{ij} = (_{SB}\{\mathbf{S}^{t}_{B} \mid \mathbf{B}$ occupies $\mathbf{H}_{kl}\ \mathbf{e}\ \mathbf{U}(\mathbf{H}_{ij}), \mathbf{H}_{kl} \# \mathbf{H}_{ij}\}$
$+$

$_{Skl}\{\mathbf{V}^{t}_{kl} \mid \mathbf{H}_{kl}\ \mathbf{e}\ \mathbf{U}(\mathbf{H}_{ij}), \mathbf{H}_{kl}$ unoccupied, $\mathbf{H}_{kl} \# \mathbf{H}_{ij}\}) / (\mathbf{N}(\mathbf{U}(\mathbf{H}_{ij})) - 1) \qquad$ **(5).**

Below we name $\mathbf{SD}_A$ *a local economic tension* of individual **A** at location $\mathbf{H}_{ij}$.

*The global economic information* available to each individual agent is given by an average of houses' values $\mathbf{V}^{t}_{ij}$ over the city:

$$\langle \mathbf{V}^{t} \rangle_{city} = {}_{Skl}\{\mathbf{V}^{t}_{kl} \mid \mathbf{k}, \mathbf{l}\ \mathbf{e}\ [1, \mathbf{M}]\} / (\mathbf{M} \times \mathbf{M}) \qquad \textbf{(6)}.$$

### 2.2.2. The cultural code.

Each human individual enters the world with an inherited genetic code, which pre-program his/her possibilities to behave and interact with other individuals when creating groups or societies. Inspired by this perspective, we suggest that every individual agent in our model enters the city with a "cultural code", which defines its possibilities for residential behavior and interactions with other agents. In genetics of qualitative features as well in studies of artificial life, it is common to represent the individual's genotype by means of a high-dimensional binary vector (Banzhaf, 1994). Below, we introduce the cultural code of an individual agent in the same manner. As emphasized in our previous papers, and at the outset of the present one, we suggest that human agents are characterized by their ability to vary, and, consequently, self-organize, in line with the dynamics and evolution of the system they belong to. We, therefore, suggest, that the cultural code of an agent and its residential behavior can change through its interaction with its neighbors, neighborhood, and the city as a whole.

### 2.2.3. Cultural characteristics.

*The cultural code* of an individual **A** is described by the **K**-dimensional Boolean vector $\mathbf{C}_A = (\mathbf{c}_{A,1}, \mathbf{c}_{A,2}, \mathbf{c}_{A,3}, \ldots, \mathbf{c}_{A,K})$, where $\mathbf{c}_{A,k}\ \mathbf{e}\ \{0, 1\}, \mathbf{k} = 1, 2, 3, \ldots, \mathbf{K}$. As a result, individuals of $\mathbf{2}^{\mathbf{K}}$ different cultural identities might exist in the city. Individuals **A** and **B** have different identities when vectors $\mathbf{C}_A$ and $\mathbf{C}_B$ differ in at least one component. Quantitatively we measure this by difference **r** between **A**'s and **B**'s identities:

$$\mathbf{r}(\mathbf{C}_A, \mathbf{C}_B) = {}_{Sk}(\mathbf{c}_{A,k}\ \mathbf{XOR}\ \mathbf{c}_{B,k}) / \mathbf{K} \qquad \textbf{(7)}.$$

The representation of *local cultural information* is related to the notion of *local spatial cognitive dissonance* of free agent **A**. Applying the general definition (Portugali, Benenson, 1995, Haken, Portugali, 1995) to the multidimensional presentation of cultural identity we define local spatial cognitive dissonance $\mathbf{CD_A}$ of agent **A**, occupying house $\mathbf{H_{ij}}$, as an average of the differences between **A**'s identity and the identities of his neighbors:

$$\mathbf{CD^t_A = {}_{SB}\{r(C^t_A, C^t_B) \mid B \text{ occupies } H_{kl} \text{ e } U(H_{ij}),\ H_{kl} \# H_{ij}\}/(N^t_{oc}(U(H_{ij})) - 1)} \qquad \mathbf{(8)},$$

where $\mathbf{N^t_{oc}(U(H_{ij}))}$ is the number of occupied houses in $\mathbf{U(H_{ij})}$.

If individuals similar to **A** in their cultural codes are segregated in the city at a certain degree, then their spatial distribution might affect the behavior of **A**. For this purpose we define *a global cultural information* $\mathbf{GD_A}$, available to free agent **A**, about the level of residential segregation of the individual agents of identity $\mathbf{C_A}$. We use the Lieberson (1981) segregation index $\mathbf{LS_{X,Y}}$ to characterize the level of segregation of a certain group **X** relative the other group **Y**. $\mathbf{LS_{X,Y}}$ is a probability for individual **A** that belongs to group **X** and located at house **H**, to meet a member of group **Y** within **U(H)**. The complete information on the residential segregation in the ***City*** at iteration **t** is given by the $\mathbf{2^K x 2^K}$ matrix of Lieberson segregation indices $\mathbf{LS^t_{X,Y}}$ for each pair of cultural identities (**X,Y**). To decrease the enormous dimensions of this description we suggest below that agent **A**'s behavior depends on the global level of segregation of its cultural group relative all the other individuals *taken together*, and denote the corresponding value of Lieberson index as $\mathbf{LS^t_A}$. The dimension of the latter description equals to the number of identities, i.e. $\mathbf{2^K}$. The values of $\mathbf{LS_A}$ below **0.2** corresponds to visually random distribution of agents of identity $\mathbf{C_A}$, while the values above **0.8** correspond to one or several domains occupied by the these individuals almost exclusively. Quantitatively, we describe the global cultural information an agent **A** accounts for as:

$$\mathbf{GD^t_A = \max\{0, (LS^t_A - LS^*)\}/(1 - LS^*)} \qquad \mathbf{(9)}.$$

Here $\mathbf{LS^*}$ is the value of Lieberson index that corresponds to visually segregated pattern, and below we set $\mathbf{LS^*}$ equal to **0.4**.

We suppose, that local and global information influence agent's cultural identity in alternative ways. High local cognitive dissonance $\mathbf{CD^t_A}$ forces an individual agent **A to change** its cultural identity, and an **A**'s reaction to the local cognitive dissonance is characterized in the model by *a sensitivity* $\mathbf{L_A}$ **e [0, 1]**. In the opposite direction, high level of segregation of individual agents of identity $\mathbf{C_A}$, forces **A to preserve** its current identity, and an agent's reaction to the global segregation is characterized by *a sensitivity* $\mathbf{G_A}$ **e [0, 1]**. Below we suggest that $\mathbf{L_A}$ and $\mathbf{G_A}$ are inherent properties of **A** and do not depend on **t**.

The change in an agent's cultural identity thus depends on two controversial tendencies. The cultural identity of an agent **A** can be changed when the local tendency to change an identity exceeds the global tendency to preserve it, i.e. when $\mathbf{L_A \cdot CD^t_A > G_A \cdot GD^t_A}$. If the latter is true, then the probability that the **i**-th component of $\mathbf{C_A}$ will be changed is proportional to the absolute value of the difference between the fraction of this component among **A**'s neighbors and its value for **A**. Additionally, we introduce the possibility for a "cultural mutation" with probability $\mathbf{r_m}$ per component of identity. As a result, for an agent **A** of identity $\mathbf{C_A = (c_{A,1}, c_{A,2}, \ldots, c_{A,i}, \ldots, c_{A,K})}$, occupying house $\mathbf{H_{ij}}$, the probability of change in the **i**-th component $\mathbf{c_{A,i}}$ of $\mathbf{C_A}$ to its negation, i.e. from unit to zero or vice versa, is

$$\mathbf{p_{A,i} = \max\{0, (L_A \cdot CD^t_A - G_A \cdot GD^t_A) \cdot ((Abs(f^t_i - c^t_{A,i}) + r_m)/(S_k Abs(f^t_k - c^t_{A,k}) + r_m \cdot K)\}} \qquad \mathbf{(10)},$$

where $\mathbf{f^t_k}$ is a frequency of **not** $\mathbf{c^t_{A,k}}$ in the cultural identities of **A**'s neighbors at iteration **t**:

$$\mathbf{f^t_k = {}_{SB}\{c^t_{B,k}\ AND\ (NOT\ c^t_{A,k}) \mid B \text{ occupies } H_{kl} \text{ e } U(H_{ij}),\ H_{kl} \# H_{ij}\}/(N^t_{oc}(U(H_{ij})) - 1)} \qquad \mathbf{(11)}.$$

We suppose that only one component of cultural identity can be changed at a time-step.

## 2.3. Model dynamics: trade off between migration and individual's change.

According to the flow-chart (Fig. 1), at every iteration, each free agent **A** in the city decides whether to move from, or to stay at, its present location. As it is shown in Fig. 2, the probability to leave a house *increases monotonously*, and the probability to occupy a new house *decreases monotonously* with an increase in either individual's economic tension $\mathbf{SD_A}$ (see formula 4) or cultural dissonance $\mathbf{CD_A}$ (see formula 8).

We calculate the probability that agent **A** will leave its house as:

$$\mathbf{p(SD^t_A, CD^t_A) = 1 - (1 - p_e(SD^t_A)) \cdot (1 - p_c(CD^t_A))} \quad \mathbf{(12),}$$

and the probability that **A** will occupy a vacant house $\mathbf{H_{ij}}$ as:

$$\mathbf{q(SD^t_A, CD^t_A, H_{ij}) = q_e(SD^t_A, H_{ij}) \cdot q_c(CD^t_A, H_{ij})} \quad \mathbf{(13),}$$

where **p** denotes the probability to leave a house, **q** denotes the conditional probability to occupy a vacant house $\mathbf{H_{ij}}$, when it is the only possible choice, and indices **e** and **c** denote economic and cultural components. A vacant house $\mathbf{H_{ij}}$ is attractive for an agent **A**, when at least four houses in $\mathbf{U(H_{ij})}$ are occupied. For details see Portugali, Benenson, Omer (1997).

The conjunction between individual, local and global factors, can lead individual agent **A** to decide to continue to occupy house **H** in spite of high economic tension and cultural dissonance. The reason, for example, might be a lack of attractive vacant houses in the city. The basic suggestion of the ***City*** model is that in such a situation the dissonance is resolved either by leaving the city, or by *change in the properties of the free agent itself.*

### 2.3.1. Free agent's behavior under increasing economic tension.

The change in the individual's status is an inherent source of the ***City*** economic dynamics. If an agent's status changes significantly faster, or slower, than the average status of the neighborhood, the agent either tries to migrate to another location or "goes bankrupt" according to (1) and migrates out of the city.

### 2.3.2. Free agent's behavior under increasing cultural cognitive dissonance.

An inherent source of the ***City*** cultural dynamics is a mu-

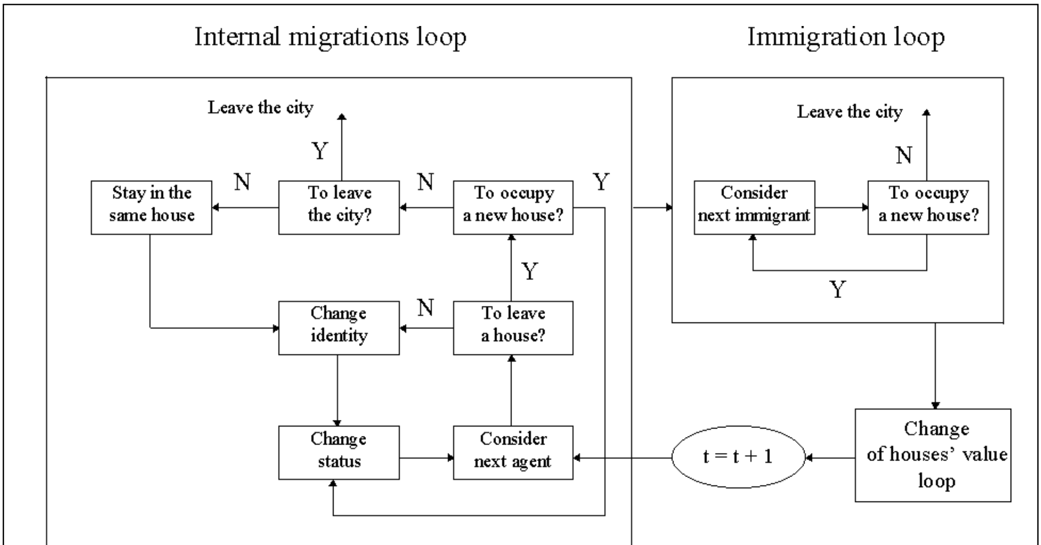


Figure 1

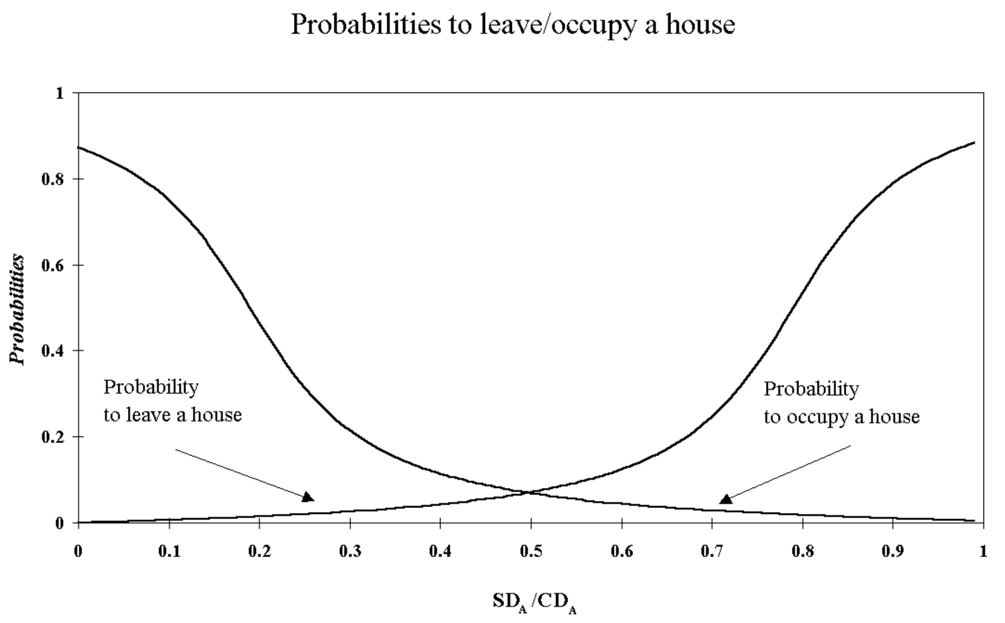


Figure 2

tation process, that prevents the ***City*** from becoming culturally homogeneous. An individual agent located in an heterogeneous neighborhood of non-zero dissonance, either succeeds to change residence, or fails and, thus, either changes an identity towards the "modal" identity of the neighbors (Fig. 1), or preserves its current identity due to high level of segregation of agents of similar identity in the city (see formula 10). Unlike the changes in the one-dimensional economic status, the changes of agents' cultural identity *do not decrease* the cultural diversity of the city when $\mathbf{K > 1}$. As an example consider the agents located at a boundary between two segregated groups of individuals $\mathbf{(0, 0, 0, \dots, 0)}$ and $\mathbf{(1, 1, 1, \dots, 1)}$. According to (10), there is a high probability that the identity of, say, the $\mathbf{(0, 0, 0, \dots, 0)}$-agent will change to a new one with a unit at one of the components and, thus, will differ from identities of the agents of *both* groups. This salient consequence of multidimensional representation of $\mathbf{C_A}$ determines most of the results below.

### 2.3.3. Emigration.

We have stated above that an individual, whose economic status reaches zero, leaves the ***City***. A free agent that failed to reside might (1) leave the City with probability $\mathbf{p_U}$; (2) change cultural identity with the probability given by (10); and (3) stay at his current location and do not change at all.

### 2.3.4. Immigration.

At every time-step, a constant number of **I** individuals try to enter the city from outside and to occupy a house in it. The economic status $\mathbf{S_I}$ and growth rate $\mathbf{R_I}$ of each immigrant **I** are assigned randomly and independently. The distribution of $\mathbf{S_I}$ is a normal truncated on $\mathbf{[min_{city}(S^{t-1}), max_{city}(S^{t-1})]}$ with a mean equals to the instantaneous mean status of the city agents $\mathbf{<S^{t-1}>_{city}}$ and constant **CV**. The distribution of $\mathbf{R_I}$ is a normal truncated on $\mathbf{[0, R_{max}]}$ and does not depend on **t**.

Cultural identity of the immigrants is assigned at random, in proportion to the current fractions of agents of each of the $\mathbf{2^K}$ possible identities.

### 3. Results.

The aim of our model is to examine the process of socio-cultural emergence in the city, the inhabitants of which can vary in their cultural identity according to potentially infinite number of traits. To qualify as a newly emerging socio-cultural entity, a group of individuals must fulfill simultaneously three conditions (Portugali, Benenson, Omer, 1997). At the **individual level** the members of the group must have the same cultural identity, at the **local level** most of the group members should be located within neighborhoods of their own, and at the **global level** the number of group members and their spatial segregation have to be sufficiently high.

Our previous studies (Portugali, Benenson, Omer, 1994, 1997, Benenson, Portugali, 1995, Portugali, Benenson, 1994, 1995, 1997) show that different sets of parameters might generate three kinds of residential dynamics in the ***City***. One is a "random" city, another is a "homogeneous" city, in which most of the agents belong to the same group, and the third is characterized by a complex structure. All these regimes are observed in the present study too, and, below, we deal with the set of parameters that entails the most interesting "structured" dynamics. In this paper we are specifically interested in the question of whether the residential distribution of the individual agents in the city evolves towards a state that can be called "persistent" in some respect and, if so, what are the characteristics of this state. In particular, what is the number, and the level of segregation, of the emerging socio-cultural entities; are they fixed? do they vanish in time? what is their "life-history"? Below we concentrate on cultural identity only and, therefore, set $\mathbf{p_e(SD^t_A) = 0}$ and $\mathbf{q_e(SD^t_A,H_{ij}) = 1}$.

#### 3.1. Parameters' value and initial conditions.

The scenarios we run share the following conditions:

1. ***City*** is a $\mathbf{40 \times 40}$ lattice.
2. Initially, at $\mathbf{t = 0}$, each cell within a circle of 3-cell diameter, located at the center of city lattice, is randomly occupied by individuals of all-zero cultural identity **(0, 0, 0, …, 0)**.
3. Immigration rate **I** equals **4**, or **0.25%** of maximum number of the city residents - **1600**.
4. Probability $\mathbf{p_U}$ to leave the city, when failing to occupy a new house, equals **0.075**
5. Distributions of sensitivities **L** and **G** are uniform on **[0, 1]**. They are assigned to the agents independently of each other.
6. Mutation rate $\mathbf{r_m}$ is **0.02**.
7. Threshold group size sufficient to recognize a group as an "entity" is **40** individuals (enabling up to 40 different identities to exist simultaneously in the city).

At present, our computer allows us to study the system behavior when the dimension of the cultural identity vector $\mathbf{C_A}$ is less or equal to **5**. The question of whether the case of **K = 5** is representative of a higher-dimensional $\mathbf{C_A}$, will be studied further.

The results below are common for five repetitions of each scenario.

#### 3.2. Presentation of the *City* patterns.

There exist certain difficulties in presenting the spatial characteristics of the city when a cultural identity is a multidimensional vector. To present the image of the city, we use below three kinds of maps. The first one is a distribution of agents' cultural identity, with each identity marked by its own color. This presentation is the most detailed one, but is unacceptable for **K > 2**, in view of high number and non-linear ordering of identities. The second type of maps is that of difference $\mathbf{r(C_A,C_0)}$ between the identity $\mathbf{C_A}$ of agent **A**, occupying house **H** and an *a priori* chosen identity that equals, say, $\mathbf{C_0 = (0, 0, 0, \ldots , 0)}$. This map shows the effects that do not depend on **K**, but its disadvantage is that several different identities $\mathbf{C_A}$ can equally differ from the selected for comparison. The third map is that of a distribution of cultural cognitive dissonance of the residents. This map is a surrogate of Stability-Instability Surface (Portugali, Benenson, Omer, 1995) in the sense that the higher is the dissonance, the higher is the chance that the state of a given house will change.

Before proceeding to the analysis, let us point out that the dynamics of the distribution of cultural identity depends

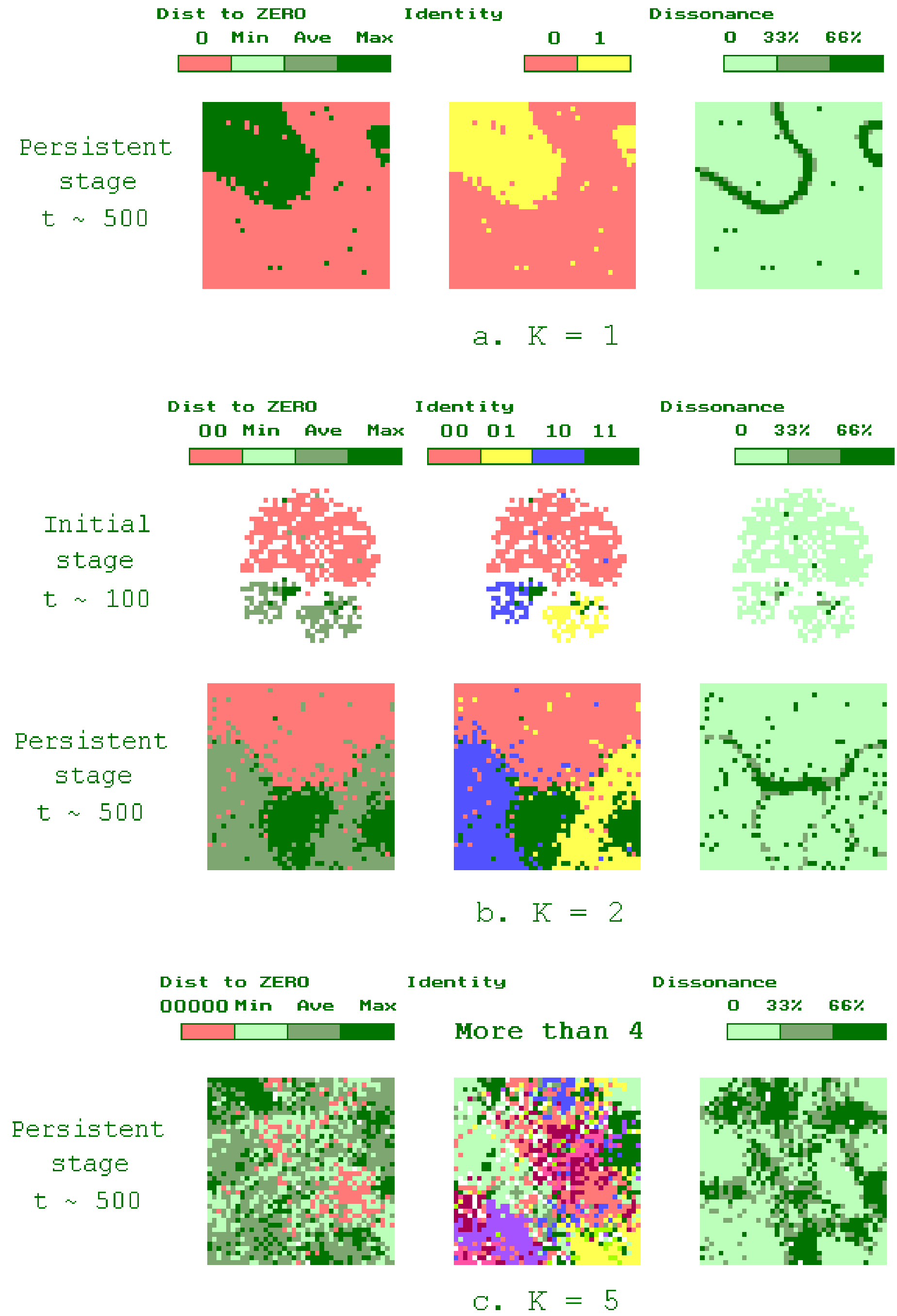
Dist to ZERO
0 Min Ave Max
Identity
0 1
Dissonance
0 33% 66%
Persistent stage t ~ 500
a. K = 1
Dist to ZERO
00 Min Ave Max
Identity
00 01 10 11
Dissonance
0 33% 66%
Initial stage t ~ 100
Persistent stage t ~ 500
b. K = 2
Dist to ZERO
00000 Min Ave Max
Identity
More than 4
Dissonance
0 33% 66%
Persistent stage t ~ 500
c. K = 5

Figure 3

on the number **K** of its components. In general, an increase in **K** increases the "resolution" of identity, but keeps the range of its variability. We mean here that according to (7) the maximal possible value of **r($C_A$,$C_B$)**, i.e. difference between individual **A** of identity $C_A$ and individual **B** of the opposite identity $C_B$ ($C_A$ = **(0, 0, 0, … , 0)** and $C_B$ = **(1, 1, 1, … , 1)**, for instance) remains equal to unit, no matter what **K** is.

### 3.3 Model dynamics for low-dimensional cultural identity: K = 1 and K = 2.

The case of **K = 1** corresponds to our previous analysis of residential segregation between two cultural groups (Portugali, Benenson, Omer, 1994). The city dynamics in that case entailed a fast self-organization of **(0)-** and **(1)-** identities within two or several segregated patches. The boundaries between the homogeneous patches remain the areas of instability, with intensive exchange of individuals (Fig. 3a, compare to Portugali, Benenson, Omer, 1994).

When **K** equals two, the dynamics of the city still resemble some of our previous results (Portugali, Benenson, 1997, Portugali Benenson, Omer, 1997). At the beginning of the runs, in line with the restriction of mutation process by one component per iteration, only **(0, 1)-** and **(1, 0)**-agents emerge. The numbers and the level of segregation of the initial **(0, 0)-** and of new **(0, 1)-** and **(1, 0)**-identities reach the levels satisfying the conditions of socio-cultural emergence, to **t ~ 100**, when the fraction of unoccupied locations in the city is at a level of 25%. The agents of **(0, 1)-** or **(1, 0)-**identities that change it to a **(1,1)** because of mutation or dissonance with the neighbors, still have the vacant houses to reside. As a result, the **(1,1)** socio-cultural entity emerges in the City (Fig. 3b) in all of the model runs to **t ~ 400**. In parallel, the number of vacant houses tends to approach zero, and strong competition for houses turns to be the factor that defines the survival of the entities. In general, the survival of a certain entity is defined by the position and the size of the domains, it occupies. The high value of the perimeter/area relation, as well as the common boundary with an opposite entity (e.g. **(0, 1)** for **(1, 0)-**agents) decreases the chance that the entity will persist. As a result, in a long run (we stopped the simulations at **t = 2500**) the number of socio-cultural entities, existing simultaneously in the city for **K = 2**, fluctuates between three and four, and the life-span of the entities is of the order of 500 iterations.

Let us now skip an intermediate cases of **K** equals **3** and **4**, and proceed with **K = 5**.

### 3.4. Model dynamics for high-dimensional cultural identity: K = 5.

#### 3.4.1 Initial stage of the model dynamics.

The number of possible identities for this case is $\mathbf{2^5 = 32}$. The first mutant agents belong to one of five "close-to-zero" identities, which are characterized by unit at one of the components and zeros at the rest of them and, compared to **K = 2**, it is *not necessary* that all of them will emerge at the first stage of the city development. In the five runs we did, their number vary between two and four.

#### 3.4.2. Persistent dynamics of the city.

The entities that emerge first determine the further dynamics of the city. In a way similar to the case of **K = 2**, the boundaries between two homogeneous domains (occupied by the entities that emerged at the first stage) and the heterogeneous domains, occupied by the agents of varying identities, are areas of instability. The agents located there, either leave their houses or change their identity. None of the properties of the certain socio-cultural entity currently existing in the ***City*** can be predicted in a long run. As a result, we cannot follow the qualitative fate of certain identity, but still are able to understand and predict are the properties of the model city as a complex self-organizing system:

1. The persistent city structure is characterized by a mixture of spatially homogeneous domains, the population of which forms socio-cultural entities, and domains that are heterogeneous at different level. The former cover about half of the city for **K = 5** (Fig. 3c).

2. A limited number of cultural entities can exist in the city simultaneously (Fig. 3c, Fig. 4).

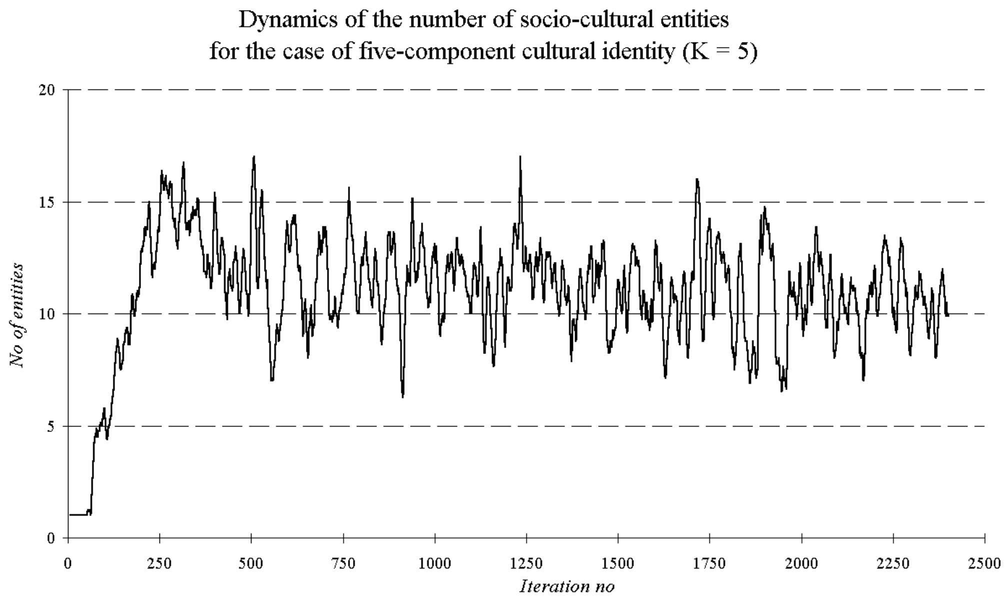


Figure 4

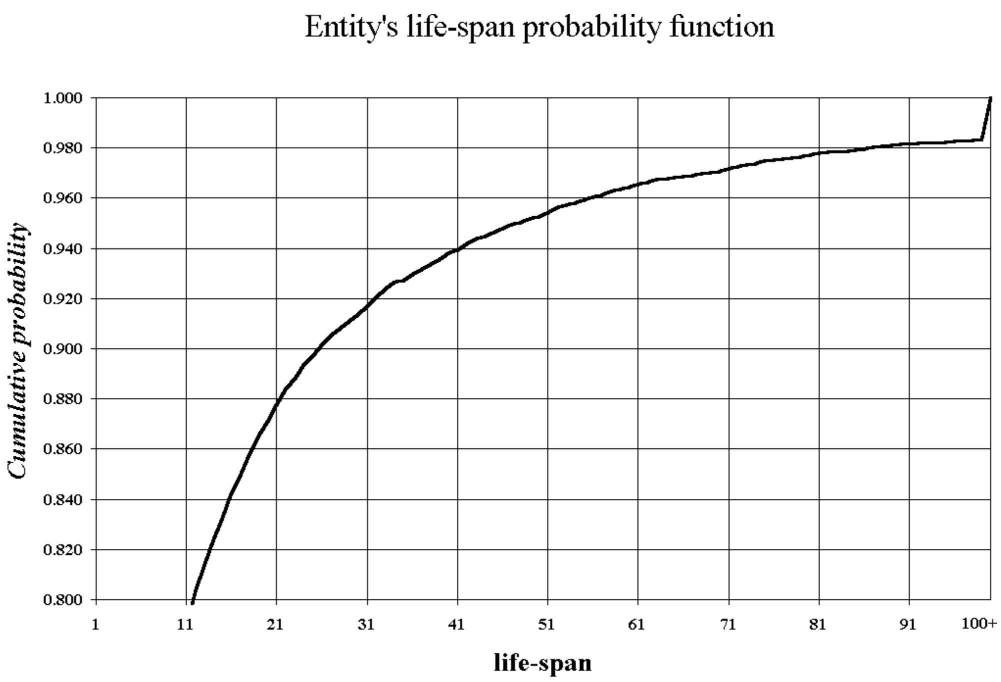


Figure 5

3. The life-span of socio-cultural entity is finite and the entities replace each other in the city space. About 20% of the entities persist in the city 11 iterations or longer and 10% persist 25 iterations or longer (Fig. 5).

4. The distribution of cultural differences $\mathbf{r(C_A,C_0)}$ between the cultural identity $\mathbf{C_A}$ of agent **A**, and certain "basic" cultural identity $\mathbf{C_0}$ ($\mathbf{C_0 = (0, 0, 0, 0, 0)}$ for the maps we present here) is self-organizing as well (Fig. 3). This distribution has two opposing characteristics. First, in general, the difference $\mathbf{r(C_A,C_0)}$ increases with the increase in the distance from the location of the agents of the $\mathbf{C_0}$ identity. Second, *non-linear ordering of the identities* implies the emergence of the adjacent areas of entities $\mathbf{C_A}$ and $\mathbf{C_B}$, that equally differ from $\mathbf{C_0}$ (i.e. $\mathbf{r(C_A,C_0)} \sim \mathbf{r(C_B,C_0)}$), but differ also among themselves (i.e. $\mathbf{r(C_A,C_B)}$ is high). See, for instance, the bottom part of Fig. 3c, where the boundary between yellow and violet domains is an area of high dissonance. This property, determined by the multidimensional and quantitative nature of cultural identity of the model agent, limits the *City's* instability *from below*. With an increase in the segregation in the city, its instability does not converge to zero (Fig. 6) and several unstable zones are preserved. We can say, thus, that the city is self-organizing and evolving toward *critical* internal structure, that preserves the ability to changes.

## 4. Conclusions and Discussion.

Our research is based on the idea, that an individual human agent is able to change him/herself, depending on information at different levels of self-organizing city structure. Such an idea implies the possibility of socio-cultural emergence in the city (Portugali, Benenson, 1997, Portugali, Benenson, Omer, 1997). In this paper, we introduce the notion of "cultural code" which describes the individual as a multidimensional and qualitative unit. From this perspective, follows three new qualitative phenomena. First, *recurrent self-organization, emergence and extinction* of the socio-cultural groups in the city. Second, *only a limited number of cultural entities* (from a large number of possible ones) can *exist simultaneously* in the city space. Third, the city as a

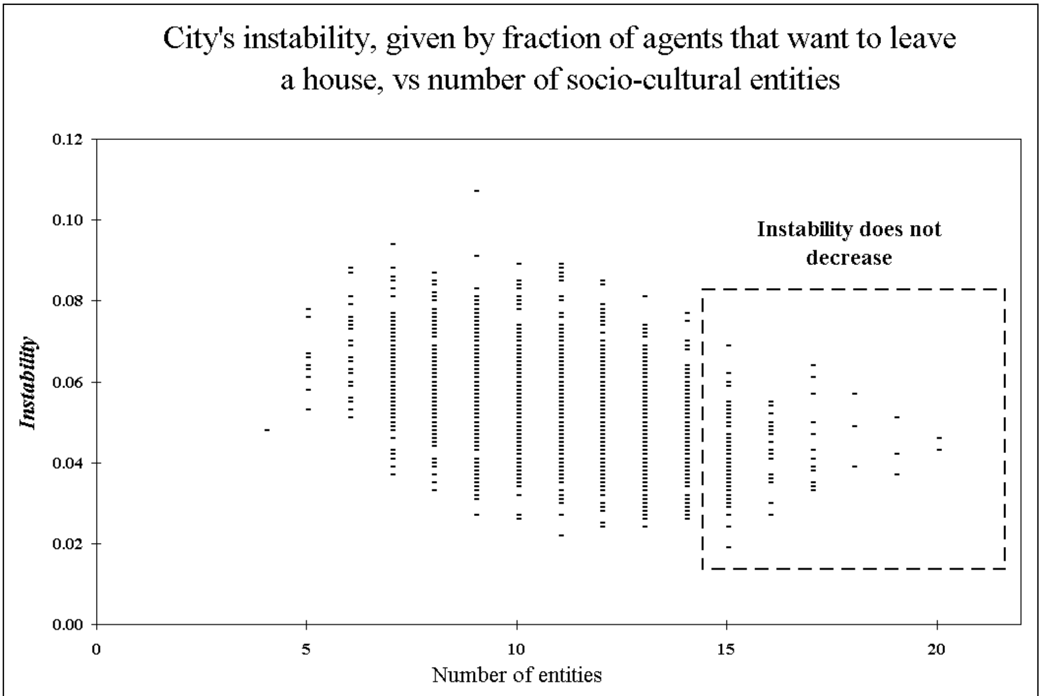


Figure 6

whole *tends towards a self-organized critical state* that preserves cultural instability. As a result, the city cultural landscape is a mixture of a few homogeneous domains, each one occupied by individuals of a certain socio-cultural identity, and areas of heterogeneous population. The identities of the existing socio-cultural entities and their further evolution depend on the emerging situation and cannot be predicted in advance.

An important question we do not discuss in the present paper concerns the consequences of the interrelations between self-organizing cultural and economic city structures. The evolution of the latter has intensively been studied during the last three decades, when most of the recent efforts are performed within the framework of the Cellular Automata models. The CA modeling clearly demonstrates effects of self-organization in the city space. (Batty, Xie, 1994, Itami, 1994, Benati, 1997, Sanders et al, 1977), The resolution of CA models is at the level of several parcels of land, and the their outcome is in good agreement with the dynamics of the real cities (Wu, 1996, White, Engelen, Uljee, 1997). The number of the cell states in CA models, which usually refer to land uses (housing, industry, commerce, etc.), is always predetermined with the implication that no new form of land use can emerge in the city. Our agent-based models operate at the level of separate individuals and houses and enable the possibility of emergence of a qualitatively new groups in the city space (Benenson, Portugali, 1995). When cultural and economic characteristics of agents are considered together, we can demonstrate coherent self-organization of the city economic and cultural landscapes (Portugali, Benenson, 1995). The phenomenon of socio-cultural emergence provides a low-resolution mechanism that enables qualitative bifurcations of the city spatial dynamics (Haken, Portugali, 1995). The construction of a comprehensive model, that combines cellular automata with the agent-based approach can be a further step towards understanding the dynamics of the city as a self-organizing system.

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