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Spatial cognitive dissonance and sociospatial emergence in a self-organizing city

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Abstract. By conceiving the city as a self-organizing system, we highlight and examine three interrelated phenomena of residential sociospatial segregation in a city: the gap which exists between intentions, preferences, and motives, on the one hand, and actual spatial behavior, on the other; the existence and role of local regions of instability within an otherwise stable urban system; and the conjunction between these two phenomena and the processes related to the emergence of new sociospatial entities. We examine the interplay between these interrelated urban phenomena and illustrate their role in urban dynamics. The discussion throughout the paper is elaborated partly by reference to empirical evidences but mainly by means of 'city games' played on a heuristic model (City-2) designed specifically for this purpose. City-2 can be described as a two-layer model composed of a migration submodel, which describes the intercity and intracity migration movements, superimposed on a cellular automata (CA) submodel describing the dynamics of the urban landscape itself. City-2 elaborates on, and extends, two previous heuristic models designed by us: (a) City, which is a probabilistic CA simulation model designed to examine the sociospatial relations between large social groups in a city, and (b) City-1, a planning-oriented cell-space model which introduced, in addition to the sociocultural properties of individuals, their economic status and the changing land value surface of the city.

Introduction

We suggest that the city be seen as an open, complex, and thus self-organizing system exhibiting the phenomena of nonlinearity, bifurcation, and phase transition, and that cellular automata (CA) and cell-space models are appropriate for describing cities as self-organizing systems and can be used as heuristic-hermeneutic tools to study their properties. We also suggest that heuristic urban models can be subject to hermeneutics in the sense that every model is an interpretation of some urban phenomenon and that the aim of our models is not to achieve 'best fits' with reality but to provide a text— albeit of a new type— which must be interpreted. We use the notion of hermeneutics to emphasize that in both cases there may be more than one 'correct' interpretation. These three suggestions form the foundations of our research project on the city as a self-organizing system, in which we focus specifically on spatial sociocultural urban phenomena.

This is the fourth paper in which this research project has been discussed. In the first paper (Portugali et al, 1994) we examined the phenomenon of residential sociospatial segregation in a city and the existence and role of local regions of instability within an otherwise stable urban system. The discussion throughout was elaborated by reference to empirical evidence and by means of 'city games' played on the City model. In the various simulations played on City, the actors were defined in terms of their intention to locate close to members of their own socioeconomic, ethnic, or cultural group. This formulation enabled us to isolate the impact of the preference for culturally or socially homogeneous neighborhoods from other complex location factors operating in the city and to trace the implications of such preferences on residential patterns. One important implication was the finding that the emergence of local pockets of sociospatial instability is governed (among other things) by a self-organization principle we

call the captivity principle, which is essential to the systemic stability and reproduction of the city as a whole.

In the second paper (Portugali and Benenson, 1995) we considered two interrelated questions: (a) the impact of international migration on intraurban migration, the urban space economy, and sociospatial segregation—the empirical case being the recent waves of Jewish immigrants from the ex-Soviet Union to Israel; and (b) the implication to planning theory and praxis of the central property of cities as self-organizing systems—that they are not predictable and controllable and in this respect not plannable (in the conventional sense of planning). We examined these questions through City-1, which is in many respects an elaboration of City. This modified version took into account not only cultural affiliation and behavioral intentions of individuals, but also their actual and potential economic situation as well as the urban land value with respect both to rented and to owner-occupied houses. It was constructed also as a planning device—a heuristic computer game whose aim is to enable planners to gain 'artificial planning experience' on the basis of which they will be better qualified to make intuitive planning decisions. City-1 was designed as a two-layer model composed of a population model of human agents (describing the migration and interaction activities of individuals) superimposed on an explicit CA model (describing the dynamics and evolution of the urban landscape).

In the third paper (Portugali and Benenson, 1994) we continued, and built upon, the work described in the second one. Perceiving cities in terms of Haken's synergetics (Haken, 1983), in which an ordered steady state is reached in the system as a consequence of a competition among some other parameters, we focused on the interplay between two order parameters which are central to the urban dynamic: the cultural order parameter and the economic order parameter. In particular we examined the nonlinear consequences of self-organization in the city in relation to sociocultural spatial segregation. It was found that, when individuals are motivated by economic preferences only, the result is a sociospatially integrated city; when cultural preferences dominate, the city is first segregative but with time spatial segregation disappears; and when individual decisions are motivated by cultural and economic preferences the city evolves from the start as a segregated city and remains segregated.

In both City and City-1 the sociocultural properties of individuals (greens versus blues and olim versus veterans) and their sociospatial intentions or wants (segregatives or neutrals) were determined externally, outside the models. The aim of the present paper is to allow for these properties to be determined internally, inside the model. Such a model will enable us to examine (a) the very dynamics of the tendencies, values, and wants of individuals, (b) the way in which a new sociospatial group with its own identity is born, and (c) the implications thereof to residential spatial segregation in the city. It is important to note that the questions of human intentionality and sociospatial emergence are central to social theory. In this context this paper, in fact, adds our theory or views on the subject. It differs from the usual discourse in social theory (and in social geography) in terms of the means employed for this purpose. In addition to, and in place of, the 'usual' hermeneutic discourse which is typical of social theory, we make extensive use of City-2 which is a specific heuristic-hermeneutic model and is described below.

Intention versus behavior

Our point of departure in this paper is a phenomenon which emerged out of the various games played on our first model City—a gap between individuals' wants, intentions, and values, on the one hand, and their actual behavior and action, on the other. Separating intentions from behavior runs counter to mainstream regional science and to urban and regional modelling which are currently dominated by a

mixture of economism and behaviorism. According to the latter, "researchers interested in a science of behavior ought to restrict themselves strictly to public methods of observation ... [and] ought to focus exclusively on behavior: researchers ought assiduously to eschew ... such concepts as plans, desires or intentions" (Gardner, 1987, page 11). By Economism we mean the assumption of the rational economic person. The result is that, in regional science, intention and behavior are usually treated as causally related; intention is the cause of behavior or, alternatively, behavior is some product of the optimization of intentions. In the model we proposed below, intention and behavior are two relatively independent entities which might affect, complement, negate, or compete with, each other. By departing in this respect from the approach of mainstream regional science, we in fact follow disciplines such as psychology or cognitive sciences (the past strongholds of behaviorism) which since the mid-1950s have turned their backs on behaviorism and today regard "the theoretical claims of behaviorism (though not its various applied achievements) ... [as] largely of historical interest" (Gardner, 1987, page 110). We also follow classical social theory and what we consider to be some of the most important implications of the theory of self-organization. These theoretical bodies provide the conceptual background to the model and theory developed in this paper. In the following sections we will present and discuss each of them in turn.

Classical social theory

The interrelation between the individual's intentions and value system, his or her actual behavior, and society, is a central theme in social theory and philosophy. The notion of ideology, for example, is related directly to the tension created between a person's value system and his or her actual behavior and action (Larrain, 1982). Such a tension often leads to what Hegel and later Marx called 'ideological false-consciousness' which obscures people's vision from the real conditions of their existence. A central debate in social theory exists between Marxists who claim that a person's value system (including intentions) is dialectically determined by their conditions of existence (that is, actual behavior) and liberal humanists who consider human action as an outcome of human intentionality. Giddens's (1986) recent theory of structuration aims to synthesize the two views: on the one hand, the individual is a free agent whose intentions determine his or her actions; on the other hand, the individual is acting in a relatively autonomous social structure with its own rules and thus his or her actions and behavior have unintended consequences.

In the last two decades, mainstream social geography has been influenced strongly by social theory and by Giddens's structuration and is thus very critical of behaviorism and its application to geography and regional science (Thrift, 1983). From the perspective of social theory it accuses behaviorists of blurring the dialectical relations between the human agency and his or her sociospatial structure. That is, the refusal of behaviorism to consider the subjectivity of the individual with his or her wants and intentions and to study the ways in which sociospatial structures such as cities determine individuals' wants, intentions, and ideas (for a more complete discussion, see Jackson and Smith, 1984, chapter 3; Gregory and Urry, 1985). The model we present below thus provides a basis to reintegrated social geography and regional science.

Self-organization theory

One of the cutting edges of regional sciences over the last few years is the theory of self-organization. Now, the very idea of self-organization with its property of nonlinear relations implies, almost by definition, a gap between intentional causes and behavioral effects, as well as various forms of unintended consequences. Furthermore, one of the logical consequences of applying the theory of self-organization to the domain

of behavior has been to discredit behaviorism. This is implicit in Prigogine's theory, especially where he criticizes "the particularly unfortunate use of concepts [such as optimization, because although] it is obvious that the management of human society ... tend to optimize some aspects of behavior ..., to consider optimization as the key ... is to risk confusing causes with effects" (Prigogine and Stengers, 1984, page 207). This is even more prominent and explicit in Haken's synergetics approach to self-organization in which the order parameter (for example, an emerging spatial pattern) enslaves individuals' behaviors. Within the domain of human behavior this was beautifully illustrated in a series of experimental and theoretical studies designed by Kelso who used Haken's synergetics approach to self-organization as the framework for his work (Haken, 1990; Haken et al, 1985; Kelso, 1984; 1990). In Kelso's experiments, intention and behavior are found to be methodologically and scientifically separated although dialectically related. Interesting discussions and results were also obtained by Stadler and Kruse (1990) with respect to cognitive processes in general. The separation of intention from behavior in the model developed below thus follows directly from our view of the city as a self-organizing system.

Cognitive dissonance

Unlike social theory and Giddens's structuration theory which is concerned mainly with society, Festinger's (1957) theory of cognitive dissonance focuses directly and exclusively on the cognitive processes of the individual. The idea is straightforward. A cognitive gap or dissonance between an individual's wants or intentions and his or her actual behavior and action is cognitively unbearable. It creates a cognitive tension which will eventually have to be resolved either by a change in behavior and action, or by a change in wants, intentions, and value system. Festinger's theory was examined in various laboratory experiments as well as in real-life observations and is now generally accepted. More recently, the theory received further support from Gazzaniga's (1985, page 80) studies on the modular structure of the brain: "the new brain science [adds to Festinger's theory] the knowledge that [cognitive dissonance is related to the fact that the brain] is organized in ... relatively independent modules that are capable of initiating disparate behavior in the first place". Cognitive dissonance as formulated by Festinger and elaborated by Gazzaniga provides the starting point to the notion of spatial cognitive dissonance which is central to our discussion.

So far, there have been only a few attempts to consider the behavioral implications of self-organization theories in urban and regional modelling and only one attempt, to our knowledge (Timmermans, 1990), to take notice of the postbehaviorism approaches which since the 1950s have been prevalent in behavioral sciences such as psychology or cognitive studies (for a discussion on these and related issues, see Desbarts, 1983; Fischer et al, 1990). As regards the first issue Fischer et al (1990) have examined (among other things) the 'master equation approach' and the 'ecological approach' in urban and regional modelling and made the distinction (further elaborated by Sonis, 1991) between two behavioral models: the economic person (homo economicus) versus the social person (homo socialis). The first "is a totally egoistic, rational omniscient creature who is supposed to accomplish rational free choice ... on the basis of the utility maximization principle", whereas the behavior of the second "is based on co-interaction [for example, among individuals] and information flows through contacts with the 'nearpeers' ... and through mass media" (Sonis, 1991, page 36). Intuitively, one could say that the social person behaves 'like others'—the more people behave in a certain way, the more people will follow—up to a certain limit, with the implication that as a whole it takes a logistic form. People might thus change their behavior as a consequence of the various sociospatial interactions in the system. As Sonis's social person behaves

like others, the original intentions or wants of that individual are of no significance and by implication no intention–behavior tension can arise and persist; the model thus conforms with strict behaviorism. Sonis's discussion of the social person remains on an aggregate '*meso* level'. It leaves open questions such as 'how many, or where in the city, people change their behavior in the process of self organization?'; 'do they change their behavior voluntarily?'; 'what happens to those who do not?'. As noted, strict behaviorism commands that "researchers ought assiduously to eschew" such questions. We say that obeying this command diffuses the achievement of Sonis's social person as it leaves the homo socialis in a no better position than the homo economicus; both concepts attempt to predetermine human nature. For the economic person, utility maximization is the prime human motivation; for the social person it is being like others. We follow the implications of self-organization and the synergetics studies on behavior and take a preliminary step toward an explicit consideration of the individual with his or her subjective wants, beliefs, and intentions, in relation to the global system—the city as a whole. Such a theorization is similar in nature to Timmermans's (1990) recommendation that students of regional science should take notice of the 'variety-seeking choice behavior' models. Elaborating on this notion, he brings various motivation theories which offer an insight into why individuals may seek variety. Among these is Festinger's theory of cognitive dissonance mentioned above, which, like other theories of this kind, distinguish, and study the interplay, between actual behavior and intention. Timmermans suggests the variety-seeking choice behavior as an addition to the usual utility maximization approach. Separating intention from behavior enables us to address one of the problems which lies at the center of social theory, social geography, and the theory of self-organizing systems: the relations between the individual and the system.

In line with our perception that the city is a self-organizing system, and with several previous attempts to consider individual cognition and behavior in terms of self-organization, it is interesting to note that Festinger's theory can easily be described by a birfurcation diagram (figure 1). That is, from the perspective of the individual, a situation of cognitive dissonance drives the individual into a cognitive bifurcation

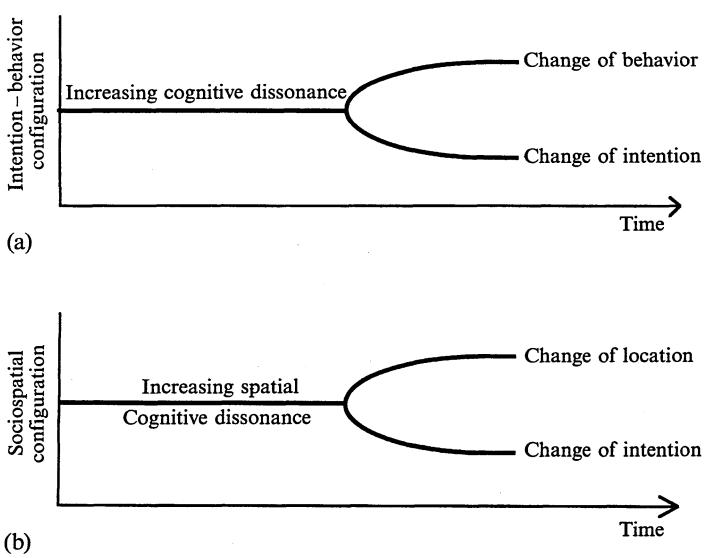

Figure 1. General (a) and spatial (b) cognitive dissonance formulated in terms of bifurcation diagrams.

point—to change behavior or to change intentions and value system. A typical case within a city would be that of an individual living in a neighborhood where he or she does not want to live. This frustrating situation can be resolved either by a change of wants, or by migration. A recent empirical examination of the intention–behavior gap, within a city context, seems to support this view. It suggests that, with time, people's reaction to the intention–behavior gap becomes polarized. People living for long period of time (more than 18 years) in a neighborhood of another cultural group (Jews among Arabs, and vice versa) become either integrative (that is, change wants) or extremely segregative in the value judgment of their actual situation. This is illustrated in figure 2.

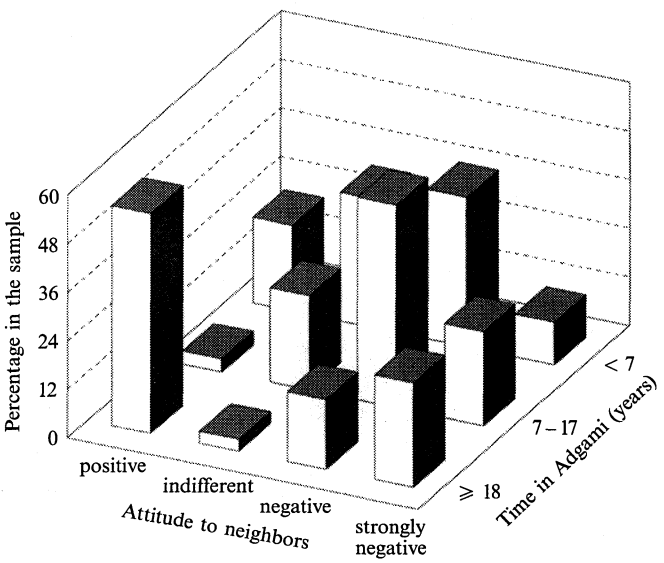

Figure 2. The changing reaction in time of Jewish inhabitants living in Adgami (the Arab community of Tel Aviv Yaffo) to their Arab neighbors. Four attitude groups were found: positive attitude about living among Arab neighbors; people indifferent as to their neighbors; negative attitude—prefer to live among Jewish neighbors; strongly negative attitude—strong objection to live among Arabs.

As noted above, this dissonance between intention and actual behavior was also obtained as a by-product from the various simulation games played on City. In our first study (Portugali et al, 1994) we used City as a mean of examining the sociocultural spatial segregation resulting from two groups of individuals (greens and blues) divided into various configurations according to their intentions: blue or green segregatives who want to reside spatially among their own kind, and blue or green neutrals who are indifferent as to their location in the city. In the various games played it was found, first, that in all the simulations there were always individuals who actually behaved (that is, were located in space) counter to their intentions (for example, a segregative green located among blue neighbors). Such people live in what we shall define as spatial cognitive dissonance. Second, in the majority of the simulation games these individuals were spatially segregated in the city, thus creating a relatively homogeneous area of intense cognitive dissonance. Third, these spatially segregated areas were also (or coincided with) the unstable regions of the city as measured by our SIS (stability–instability) index. This is illustrated in figure 3.

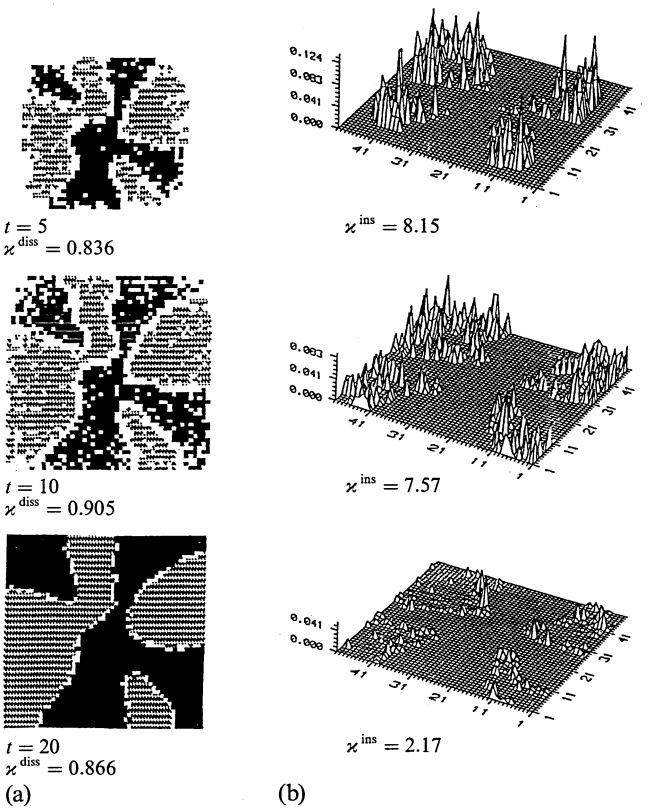

Figure 3. Results from simulation games on the model City: (a) evolution of spatial segregation of two sociocultural groups ($\varkappa^{diss}$ is the dissimilarity index); and (b) the corresponding stability and instability surfaces ($\varkappa^{ins}$ is an index of instability).

The model

The standard two-dimensional CA model as originally formulated (Toffoli and Margolus, 1987) is a lattice of cells, each of which can be in one of k possible states: $\{S_1, S_2, ..., S_k\}$. The dynamics of the cell lattice can be described as follows:

$$S_\alpha^{t+1} = f[S_\alpha^t, U(S_\alpha^t)], \tag{1}$$

where S_α^t is the current state of cell α, $U(S_\alpha^t)$ is the current state of some neighborhood of the cell, f is the transformation rule according to which the new state of α is selected out of $\{S_1, ..., S_k\}$, depending on its current state, S_α^t, and on the current state of its neighborhood, $U(S_\alpha^t)$.

This formulation is formally and intuitively attractive to urban and regional modelling. CA models, like real cities, are also built of discrete spatial units and, like houses and lots in real cities, the properties of the spatial units in CA models (the cells) are determined in relation to their immediate neighbors (Couclelis, 1985, 1988; Phipps, 1989; Portugali et al 1994; Tobler, 1979). Yet at the same time the above formulation is also limiting. This is because CA models were originally designed with reference to physical and biological systems whose main actors are spatially fixed (tissue cells, molecules, etc). Such open and complex systems interact with their environment by exchanging matter and energy through their boundaries. The city as an open complex system exchanges with its environment not only matter and energy but also human population. Interregional (or intercity) migration forms the interactive links between a

city and its environment, and intraregional migration plays an important role in the internal dynamics of cities. Immigrants are free human agents in the sense that they act intentionally but their activity occurs on the cell space of houses, parcels of land, and so on. In formulating our urban models we have attempted to take into consideration the cellular and the human components of the city structure.

Our first model, City, was thus defined as follows:

$$S_\alpha^{t+1} = \mathrm{f}[S_\alpha^t, U(S_\alpha^t), B^t]. \tag{2}$$

As can be seen, here the transformation rule depends on an additional argument B, which is the 'state vector' of the system of cells and consists of the fraction of the cells in each of the possible states $\{S_1, S_2, ..., S_k\}$. The above formulation attempts to take account of the properties of the human agency and at the same time to remain as close as possible to the original CA formalism. This is achieved because the human properties appear in the model either implicitly or as external input to it—as the rules of the game.

In our next model, City-1, the human properties of the actors appear explicitly as integral elements of the model. This is achieved by constructing City-1 as a two-layer model: a population model of human agents, describing the migration and interaction activities of individuals, superimposed on a CA infrastructure describing various domains of the urban landscape. The general structure of the model can be written as follows:

$$\begin{aligned} S_\alpha^{t+1} &= \mathrm{f}[S_\alpha^t, U(S_\alpha^t), B^t], \\ T_\alpha^{t+1} &= \mathrm{g}[S_\alpha^t, U(S_\alpha^t), B^t], \end{aligned} \tag{3}$$

where T_α^t is a state of a human agent occupying cell α, and g is an additional component of the transformation rules, defining the state of an agent, occupying cell α at the next time step.

The model City-2 used here is structurally similar to City-1 as formulated above. It differs in that it is designed specifically as a heuristic tool to examine, first, the circumstances by which spatial cognitive dissonance in the city may arise and lead to changes in the intentions, cultural affiliations, and identities of individuals and, second, the implications thereof to residential spatial segregation in the City. City-2 thus has the same structure as given by equations (3) with the addition that state T_α^t consists of two components: economic and cultural.

Like City-1, City-2 is a two-layer model: a population layer composed of individuals (persons, families, or households) with their cultural and economic properties, and a housing-stock layer composed of a two-dimensional lattice of cells (that is, houses) with their properties. The individuals who enter the city (immigrants) and those living in the city (inhabitants) interact with each other and with the system of cells or houses and this interaction results in (a) intracity and intercity migration dynamics, (b) changes in the properties of individuals, and (c) changes in the properties of the cells.

The city population

The population of City-2 is composed of individuals: inhabitants of the city, immigrants who try to enter it, internal immigrants who try to change location within it, and emigrants who leave it. Each individual has a specific intention to live among individuals who have a certain cultural identity. There are two types of cultural identity: original identity with which that individual starts the game, and current identity which refers to the individual's identity in any specific iteration of the game.

At the start of the game, original and current identity are equal and there are only blue individuals whose intention is to live among blue neighbors, and green individuals

who intend to live among green neighbors. All individuals at this stage are segregatives in the sense that their intention is to locate spatially among neighbors of their own kind. This applies also to all new immigrants when they first come to the city. The original identities with their implied intentions might change in the course of the game to become current identities and intentions. That is to say, individuals might become neutrals (indifferent as to the 'blueness' or 'greenness' of their neighbors), blues might change into greens, and a totally new sociospatial identity might emerge. In addition, each individual has a current (that is, changing) economic status and also an economic tendency. The latter is fixed throughout the game. Thus, individual P has an original cultural identity (with implied intentions) I_P^{orig} ($I_P^{\text{orig}} \varepsilon \{\text{blue, green}\}$) and a current cultural identity (with implied intentions) I_P^{cult} ($0 \leqslant I_P^{\text{cult}} \leqslant 1$), where the original green identity is equal to 0 and the blue identity to 1, economic status S_P ($0 \leqslant S_P \leqslant 1$) and economic tendency T_P ($0 \leqslant T_P \leqslant 1$). I_P^{cult} and S_P depend on time and we mark it explicitly when necessary.

The city housing stock

As noted, the infrastructures of City-2 is a $n \times m$ lattice of cells or houses (60×50 in the simulations below). Each house can be either vacant or occupied. An occupied house obtains a cultural property: blue if occupied by a blue individual, green if occupied by a green, and so on. We consider as a neighborhood of house H all cells or houses in the 5×5 square with H in the center:

$$U(H_{ij}) = \{H_{kl} | \text{maximum}(0,\ i-3) < k < \text{minimum}(n,\ i+3),$$
$$\text{maximum}(0,\ j-3) < l < \text{minimum}(m,\ j+3)\}. \tag{4}$$

Thus the neighbors of an individual P in house H (P_H) are the individuals occupying houses in $U(H)$. Every vacant or occupied house might also have a cultural image calculated as an average of the cultural properties of its neighbors and of its inhabitant. In a similar way every house also has an economic value V_H ($0 \leqslant V_H \leqslant 1$) calculated as an average of the economic status of its resident, its neighbors, and the value of the unoccupied houses in $U(H)$. We denote the payment for occupying house H as W_H ($0 \leqslant W_H \leqslant 1$).

The queue

New immigrants who want to enter the city, and inhabitants who have left their previous house in the city and were not successful in finding a new location, join the queue, from which, in turn, they 'try' to find a house in the city at the next time step.

The game

A typical city simulation game starts with a small area occupied by individuals whose original cultural intention is assigned randomly as blue or green. At each time step a constant number of individuals enter the city. Their initial cultural identities and implied intentions are also either blue or green. The initial status and tendency of the individuals are assigned randomly and independently according to given normal distributions with mean and standard deviation depending on the origin of the individual. The mean and variance of the initial economic status and tendency could also differ for individuals of different origin.

Spatial cognitive dissonance and its implications

As discussed above, spatial cognitive dissonance arises when an individual behaves (that is, is located in a certain house) counter to his or her intentions. Let us define cultural cognitive dissonance for an individual P occupying house H, ΔI_P^{cult}, as

$$\Delta I_P^{\text{cult}} = I_{\text{neighbors}} - I_P^{\text{cult}}, \tag{5}$$

and the economic dissonance, ΔS_P, as

$$\Delta S_P = S_{\text{neighbors}} - S_P , \tag{6}$$

where

$$I_{\text{neighbors}} = \frac{1}{N}\sum_G \{I_{R_G}^{\text{cult}} | G \in U(H),\ G \neq H\},$$

$$S_{\text{neighbors}} = \frac{1}{N}\sum_G \{S_{R_G} | G \in U(H),\ G \neq H\}.$$

N is the number of neighbors; $I_{\text{neighbors}}$ and $S_{\text{neighbors}}$ are the mean cultural identity and mean status of the neighbors. We will use the distribution of $I_{\text{neighbors}}$ as a cultural image of the city. The individuals in the queue try to locate in a house that satisfies their intentions; the lower the absolute values of ΔI_P^{cult} and ΔS_P for some house H the higher is the chance that an individual P locates at H.

Let us consider, for example, a blue individual who is segregative by intention and is located in a house where the neighbors (in the 5×5 square around it) are all green. This individual will try to resolve this tension between intention and behavior by leaving his or her house and buying or renting another house in the city, by leaving the city and joining the queue, or simply by leaving the system. This involves the following sequence of decisions (figure 4).

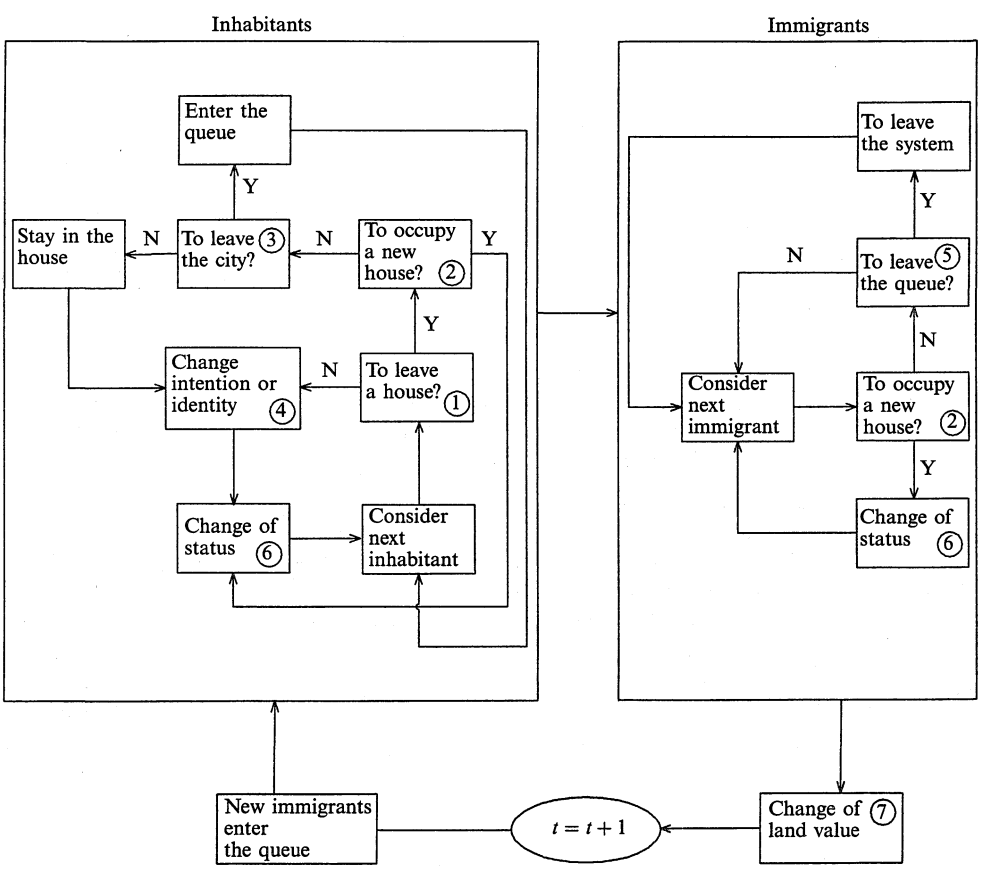

Figure 4. The flowchart of City-2.

1 *To leave the house?*
The probability R_P for an individual P to leave house H depends on the absolute values of cultural and economic dissonance:

$$R_P = \alpha_1 + \beta_1 \exp[\gamma_1 \text{abs}(\Delta I_P^{\text{cult}})] + \beta_2 \exp[\gamma_2 \text{abs}(\Delta S_P)]\,. \tag{7}$$

We choose α_1, β_1, and γ_1 such that R_P increases monotonically with the increase of $\text{abs}(\Delta I_P^{\text{cult}})$ and $\text{abs}(\Delta S_P)$; (figure 5).

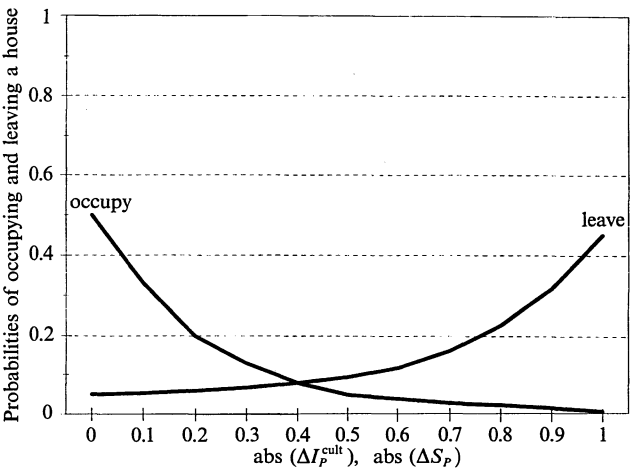

Figure 5. The repel and attractivity functions in City-2.

2 *To occupy a new house?*
This condition is applied to queuing individuals who want to enter the city as well as to residents who want to change their houses. First, an individual P can occupy house H of value V_H if his or her status and tendency are sufficiently high relative to the value of the house:

$$S_P > \delta_0 + \delta_1 V_H, \qquad T_P > \tau_0 + \tau_1 V_H, \tag{8}$$

where δ_0, δ_1, τ_0, and τ_1 are constants. Second, an individual P chooses a house from the set of vacant houses satisfying conditions (8). The 'attractivity' of a house H for an individual P, $Q_P(H)$, is estimated as follows:

$$Q_P(H) = \alpha_3 + \beta_3 \exp[\gamma_3 \text{abs}(\Delta I_P^{\text{cult}})] + \beta_4 \exp[\gamma_4 \text{abs}(\Delta S_P)]\,. \tag{9}$$

We choose α_3, β_3, and γ_3 such that $Q_P(H)$increases monotonically with a decrease in $\text{abs}(\Delta I_P^{\text{cult}})$ and $\text{abs}(\Delta S_P)$, and interpret attractivity as the probability of occupying a vacant house H when it is the only available choice (figure 5).

An individual occupies one of the houses satisfying conditions (8) or fails to occupy any of the houses in the following way. Let us denote the set of houses satisfying conditions (8) as Λ, and let H_0 represent the failure of the attempt to occupy. We define the probability p_{ij} of occupying house H_{ij}, $H_{ij} \in \Lambda$, as

$$p_{ij} = \frac{s_{ij}}{\sum_{H_{ij} \in \Lambda} s_{ij}} \tag{10}$$

where

$$s_{ij} = \frac{Q(H_{ij})s_0}{1 - Q(H_{ij})},$$

$$s_0 = \prod_{H_{ij} \in \Lambda} [1 - Q(H_{ij})].$$

3 *To leave the city?*
An inhabitant who tries to move to a new house and does not succeed will either continue to occupy the current house (with its high cognitive dissonance) or leave the city and join the queue. We assume that the probability that individual P leaves the city during an unsuccessful search, L_P, is constant:

$$L_P = \text{constant}. \tag{11}$$

Another reason for leaving the city is an economic one. If an individual's status for the current time step, $S_P(t)$, is below some threshold level, S_{th}, that is

$$S_P(t) < S_{\text{th}}, \tag{12}$$

then he or she leaves the city and joins the queue.

4 *Change in intentions*
If, for some reason, the above attempts to resolve cognitive dissonance fail, the individual remains in his or her current cell or house and the tension between intention and behavior persists. The results would be a change in that individual's intention: the individual will become either more segregative or more neutral. For a segregative blue individual this would mean becoming 'more blue' than before in terms of intentions (that is, more segregative) or 'less blue', and more neutral, in the sense that he or she will become more indifferent to the neighbours. The change in cultural intention for individual P located at house H is calculated in the following way:

$$I_P^{\text{cult}}(t+1) = I_P^{\text{cult}}(t) + \phi \Delta I_P^{\text{cult}}(t), \tag{13}$$

where ϕ is a random variable distributed uniformly over the interval $[a, b]$, $-1 \leqslant a < b \leqslant 1$. At this stage we are not considering the possibility of increasing segregativity and set $a = 0$. Queuing individuals do not change their cultural affiliation.

Sociospatial emergence
Spatial cognitive dissonance can result in changes in the individual's intentions and location preferences. An originally blue or green segregative might gradually change cultural intention and become a blue or green neutral. For a neutral $1/3 < I_P^{\text{cult}} < 2/3$, for a blue segregative $2/3 < I_P^{\text{cult}} < 1$. For neutral individuals $\text{abs}(\Delta I_P^{\text{cult}}) < 2/3$ for all possible neighborhoods and thus the repel function (7) depends weakly on $\text{abs}(\Delta I_P^{\text{cult}})$. This can be seen in figure 5.

As defined above, from the locational point of view, the level of segregativeness–neutrality forms one of the cultural ties between the individual and his or her original cultural group. Being neutral thus implies weaker cultural ties. Neutral individuals may find themselves in, or in between, the following three spatial situations: among neighbors of the original cultural group; among neighbors of the other cultural group; or among neutrals of the two groups. Whereas the first two situations will not affect the cultural composition of the city (green or blue individual), the third situation might do exactly this – it might give rise to a new cultural identity. Blue or green neutrals, located spatially among neutral neighbors (in the 5×5 cells around them) for a sufficient period of time, may acquire a new cultural identity and become 'red'. In the present

model this will happen if, at the same time, most neutrals in the city are in a similar locational situation. More formally, neutral will acquire a new cultural identity and become red, if two conditions are satisfied simultaneously: first, the neutral individual must have a majority of neutrals in the neighborhood of 5×5 houses around his or her house; and second, the majority of neutral individuals in the city as a whole must be in a similar situation.

We use the Lieberson (1981) isolation index, xP^*x, to check this second condition:

$$xP^*x = \sum_{i=1}^{N} \frac{x_i/X}{x_i/z_i}, \tag{14}$$

where X is the total number of individuals in group X, x_i is the number of individuals of group X in the neighborhood i, z_i is the total population of the neighborhood, and N is the number of neighborhoods. xP^*x gives the probability that individual P of group X living in neighborhood $U(P_H)$ will find in the same neighborhood another person from group X. In terms of the Lieberson index the above conditions mean that xP^*x for neutrals is sufficiently high. In the discussion below we let $xP^*x = 0.6$, which implies that the red cultural entity will emerge when xP^*x for neutrals is greater than this value and will include only those neutrals 60% of whose neighbors are also neutrals[1].

In the queue

The queue is composed of new immigrants and residents of the city who have left their houses. At each time step every individual in the queue examines his or her situation and takes a sequence of decisions: 'to buy a house'; 'to rent a house'; 'to wait in the queue'; or 'to leave the queue' (figure 4). The first two decisions are calculated as defined above. The last two decisions are calculated in the following way:

5 *To wait in or leave the queue?*

An individual entering the queue is trying to occupy a house at each time step. If he or she does not succeed in occupying a house during some predetermined time steps (t_{th}), he or she leaves the system:

$$t_{th} = \text{constant}. \tag{15}$$

A new immigrant who fails to occupy a house and does not leave the system returns to the queue.

Further structural changes in the city

The above sequence of decisions entails the cultural structural changes associated with cognitive dissonance and also some structural changes associated with the economic properties of the individuals and the cultural and economic properties of the housing

[1] Helen Couclelis and a student of hers have made two comments on our intention-behavior discussion and model. First, that 'intentions' should be distinguished from 'wishes' and that only intentions are relevant for modelling behavior. We accept this point and indeed this is the way we use the term intentions. We would like to add that an even more precise term would be *behavioral intentions* (Ajzen, 1991; Fishbein and Ajzen, 1975). Second, they question our spatial cognitive dissonance model in which intentions at time t are confronted with behavior at times $t+1$, $t+2$, $t+3$, ... According to them, if at time t a certain behavior (for example, migration move in the city) was motivated by a certain intention (to live among greens) in a consistent way, then the fact that at time $t+1$ the migration act did not succeed in fulfilling its motivating intention is immaterial. We do not accept this view. The crucial test here is what was the original behavioral intention. If it was 'to migrate from i to j', then they are right. But if it was, as in our model, 'to live among greens or blues', then we are right. The lesson to be learnt is that it might be useful to distinguish also between temporally single-act and temporally continuous behavioral intentions and actual behaviors. We are indebted to Couclelis and her student for their comments, which have allowed us to clarify these points.

stock itself (that is, the landscape of cells or houses). The following structural changes take place.

6 *Change of status*
Simultaneously with the above activities related to spatial location, the individual's economic status changes at every time step. The status, at the next time step, of individual P located at house H depends on his or her current status, tendency, and payment in the following manner:

$$S_P(t+1) = \begin{cases} \text{maximum } \{0,\ S_P(t) + T_P - W_H[V_H(t)]\} & \text{if } T_P - W_H[V_H(t)] < 0 \\ \text{minimum } \{1,\ S_P(t) + T_P - W_H[V_H(t)]\} & \text{if } T_P - W_H[V_H(t)] > 0. \end{cases} \quad (16)$$

We define payment $W_H[V_H(t)]$ as the right-hand side of equation (8):

$$W_H[V_H(t)] = \tau_0 + \tau_1 V_H(t). \quad (17)$$

Queuing individuals have no payment and, consequently, the changes in their status are determined as follows:

$$S_P(t+1) = \text{minimum } \{1,\ S_P(t) + T_P\}. \quad (18)$$

7 *Change of value*
The value of a vacant house H at the next time step is defined as the average of the status of individuals occupying houses or the value of the vacant houses in the neighborhood $U(H)$. That is,

$$V_H(t+1) = \frac{D}{25}\{S_{\text{neighbors}}(t) + [V_1(t) + V_2(t) + V_3(t) + \ldots]\}, \quad (19)$$

where D, $D < 1$, is a decrement of value, and $V_i(t)$ are values of vacant houses in $U(H)$.

Change in the cultural image of houses
The cultural image of the house H occupied by an individual P at time step t is equal to the value of $I_{\text{neighbors}}(t)$. It changes according to the changes in the cultural intentions $I_P^{\text{cult}}(t)$ of the individuals in the occupied cells or houses of neighborhood $U(H)$.

City-2 as a heuristic-hermeneutic model
In the introduction we suggested that City-2 be seen as a heuristic-hermeneutic model. Heuristic in the sense that its aim is not to achieve the best fit with reality but to serve as a means of discovering various sociospatial properties of the city as a self-organizing system. This is achieved, at least partly, by means of hermeneutics, that is, "free" phenomenological interpretation which is "evidenced by the senses" (The Concise Oxford English Dictionary. For discussions on hermeneutics as a method and philosophy, see Bleicher, 1980; Levi, 1986). From this perspective City-2 is a hermeneutic model in three respects. First, the model itself, as constructed above, is a phenomenological interpretation of reality. Second, City-2 aims to simulate the city as a self-organizing system and it thus exhibits phenomena of nonlinearity and randomness. As a consequence, each run or game of City-2 produces a different sociospatial scenario and configuration, that is, a different 'text' or interpretation of the possibilities in a given situation. Third, these scenarios or sociospatial configurations provide the text for us to interpret – an interpretation which is, at least in part, phenomenological and evidenced by the senses (for example, by observing various sociospatial configurations as they evolve on the screen). For a phenomenological approach to self-organization in general and to synergetics in particular, see Haken, 1993; Weidlich, 1994; Wischert and Wunderlin, 1993.

The interpretation screen

Every simulation game on City-2 implies a recursive process by which at each time step the city changes in line with the rules of the game as defined in the above model and in line with the various parameters as set at the start of the game. In order to fix the parameters we have devised the 'starter screen' on which, at the start of the game, the player can determine or change some parameters (see figure 2 in Portugali and Benenson, 1995).

The main device for interpretation is the 'interpretation screen', on which the player can observe various aspects of the city as it evolves. The screen used by us is illustrated in figure 6. For the purpose of this study we present in the interpretation screen four maps. From left to right they are: the original cultural identity of the inhabitants, their current identity, the cultural image of the houses or cells, and their economic value. It is important to note that these maps represent our choice as to what is specifically relevant and important to the issues discussed here. In previous studies we constructed other maps such as the 'stability–instability surface' (SIS), economic status maps, and so on. These economic parameters are built into the present model and affect the various processes in it, but owing to a limitation of space we will not discuss them here. However, we hope to do so in a subsequent paper.

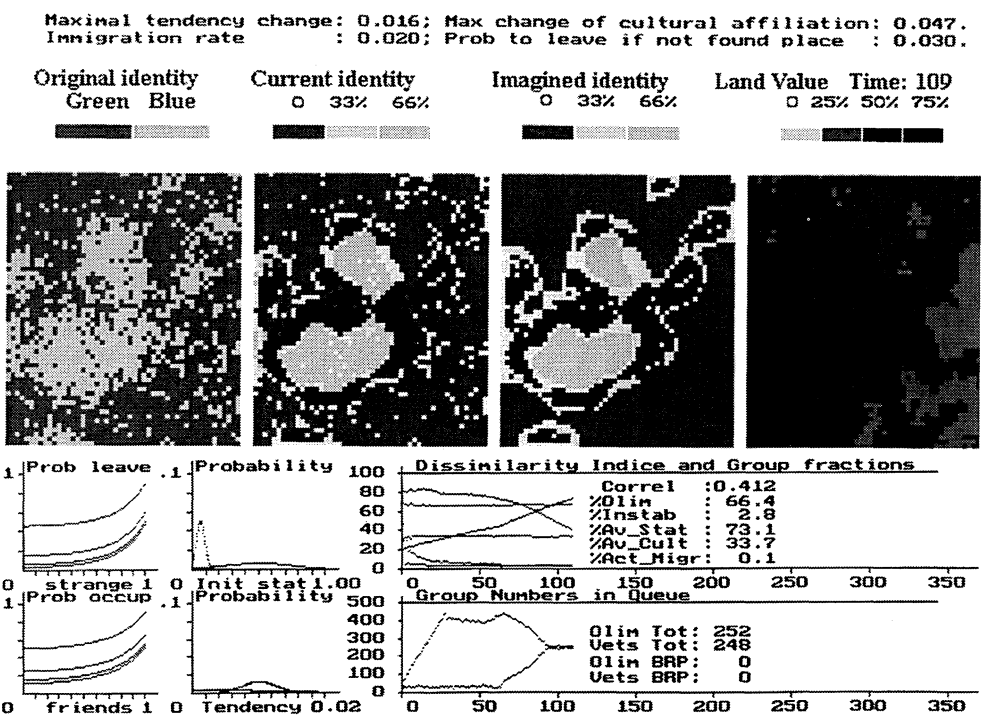

Figure 6. The interpretation screen of City-2 (green and blue are two cultural groups).

Partial results and interpretations

City-2 was designed such that the forces responsible for its dynamics are partly socio-cultural and partly economic; in fact City-2 was designed specifically to illustrate the conjunction between the two. As mentioned earlier, we will leave the full discussion to a subsequent paper and in this section present results which bear directly on spatial cognitive dissonance as resulting from the gap between intention and behavior,

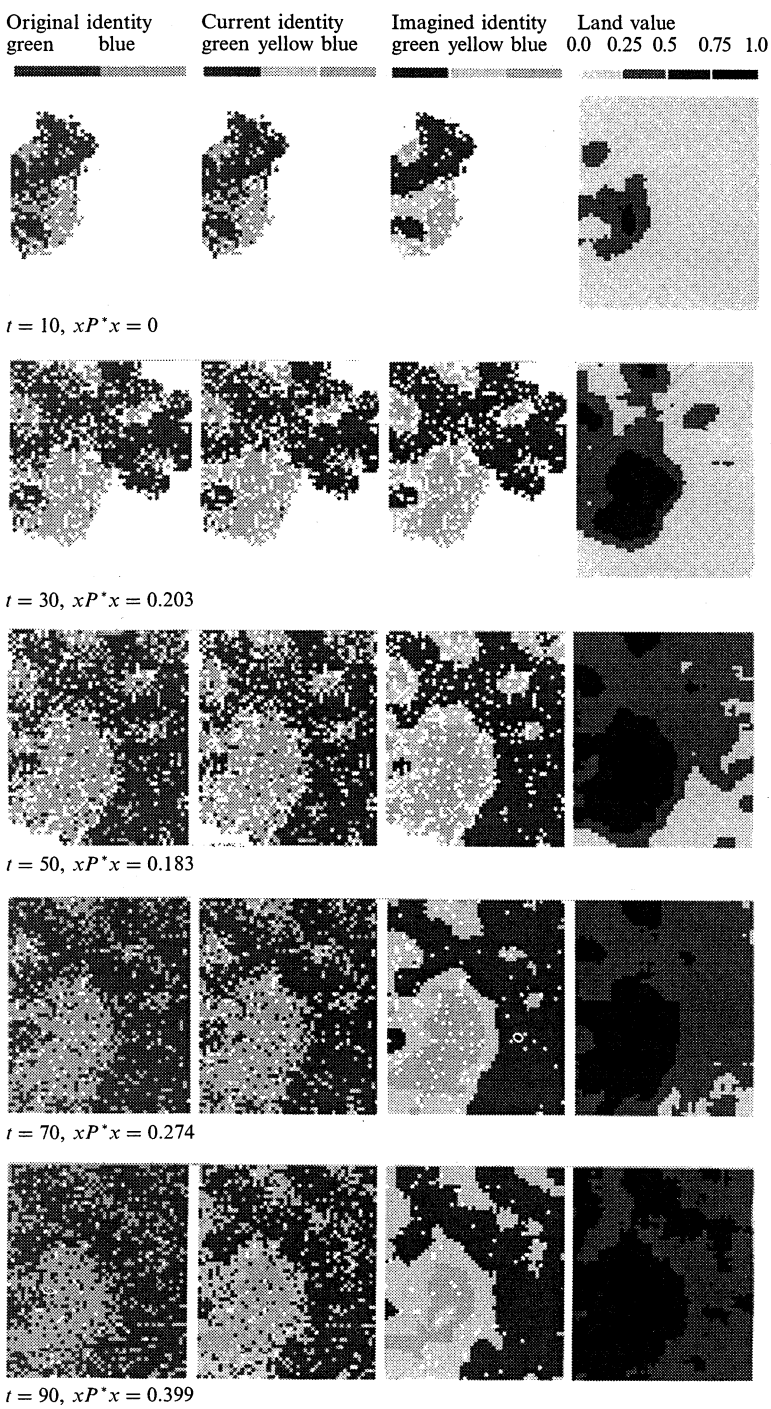

Figure 7. Several snapshots from the evolution of scenario H_3. xP^*x is the Lieberson index for neutrals. Green and blue are two cultural groups, and yellow symbolizes green or blue neutrals.

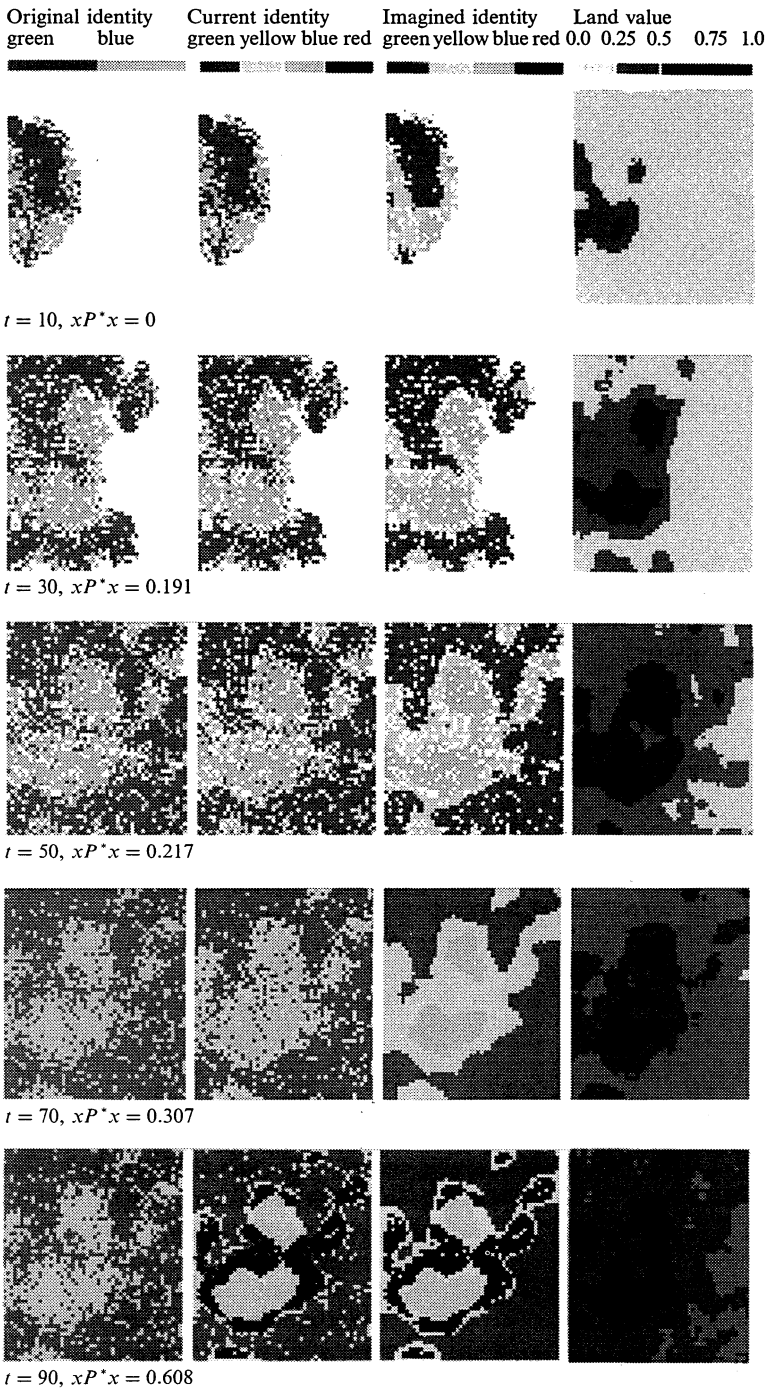

Figure 8. Several snapshots from the evolution of scenario L_3. xP^*x is the Lieberson index for neutrals. Green, blue, and red are three cultural groups, and yellow symbolizes green or blue neutrals.

its relation to the emergence of a new sociospatial entity, and the implications to residential segregation in the city. To study the above phenomena we examined on the interpretation screen a number of scenarios, or simulation games, of the city's evolution. Here we will discuss scenarios which differ in two parameters: in the probability of individuals leaving the city [L_P in equation (11)], and in the mean sensitivity of individuals to a situation of spatial cognitive dissonance [ϕ in equation (13)]. We present and interpret here two series of runs: one with a very low probability of leaving the city ($L_P = 0.01$), and the other with a high probability ($L_P = 1$). In each of the two series we consider six different values of ϕ, varying from 0.01 to 0.06, and denoted as L_1, ..., L_6 for the low probability scenarios and as H_1, ..., H_6 for the high probability scenarios. We run each scenario for 100 iterations and fix the threshold for transforming neutral blue or green into red, that is, the Lieberson index at 0.6.

Let us consider figures 7 and 8, which represent several snapshots from the evolution of scenarios H_3 and L_3, respectively. In both figures the second map from the left shows the changes in intentions and cultural identities as they actually evolve in space and time. To enable us to identify the neutrals as they evolve, we have colored them 'yellow'. By comparing the maps in the two figures, we can see how, as a consequence of the urban dynamics, in both scenarios the intentions of a growing number of blue and green individuals are being transformed gradually from those of segregatives into those of neutrals. However, although in both scenarios neutrals are created, it is only in figure 8 that some of them change their cultural identity and become reds. That is, only in scenario L_3, where the level of internal migration is low, do neutrals become exposed spatially to other neutrals to such an extent that their Lieberson index crosses the threshold of 0.6, and a new sociocultural entity—red—emerges in a process of self-organization.

This phenomenon by which sociocultural spatial segregation leads to spatial cognitive dissonance and then to the emergence of a new sociospatial identity has been termed spatial dialectics (Portugali, 1993). In that book it was shown that spatial dialectics was, and still is, an important force behind the emergence and space–time diffusion of nationalism as a social order parameter and that it played an important role in the creation of the Palestinian national identity, as well as in the emergence of the Israeli Arabs as a distinct sociospatial entity. Similar results, on an intraurban scale, are currently emerging from an ongoing study in Adgami (the Arab community of Tel Aviv Yaffo): local Arab inhabitants of Adgami tend to dissociate themselves strongly from other Palestinian Arabs living in their neighborhood despite the fact that they are all Palestinian Arabs.

An interesting aspect of the above process of spatial dialectics and the emergence of the reds as a distinct sociospatial entity concerns the space–time morphology of this change. First, by studying the evolving maps in figure 8 we can see that the appearance of the reds is abrupt—they appear suddenly at about $t = 80$ in the city. Observing the process from $t = 0$ to $t = 80$ we know that this dramatic appearance was preceded by a relatively slow and lengthy process during which, as a consequence of spatial cognitive dissonance, blue and green segregatives have been transformed into neutrals (yellows), thus paving the way for the visual bifurcation which followed. From figure 9 we learn that the process was not linear; there was one jump at about $t = 10$ when neutrals first appear, and another one (apparently the one associated with the emergence of the reds) at about $t = 60$.

The nonlinear and bifurcative form of the process is even more apparent in figure 10 describing the time evolution of the Lieberson indices associated with scenarios L_1, L_6, H_1 and H_6. Again we see that the L_1, H_1 scenarios do not take off but the L_6, H_6

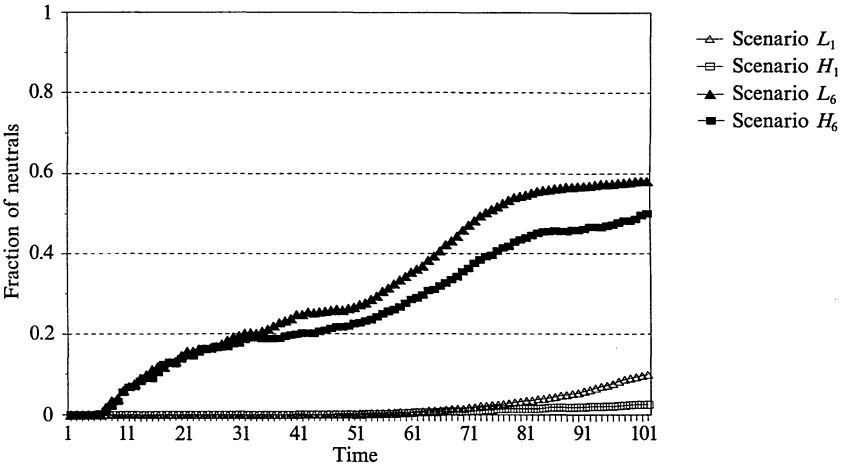

Figure 9. Growing fraction of neutrals in selected scenarios.

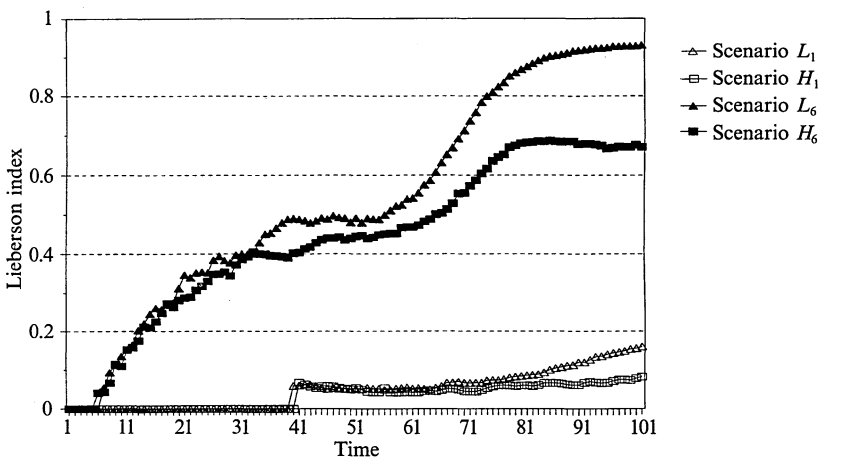

Figure 10. The time evolution of the Lieberson index for selected scenarios.

scenarios do—two jumps or a combined sequence of two S-shape curves can be observed: the first curve starts at about $t = 5$ when neutrals first appear, speeds up to $t = 30$, then slows down and does not change much until $t = 60$. Then a second S-shape process begins, speeds up, crosses the Lieberson threshold, finally to stabilize and once again become flat from $t = 70$ onward. The first half of the process is associated with the emergence of neutrals, whereas the second half describes the emergence of the reds.

Further insight into the relations between L_P, ϕ, and xP^*x can be gained from figures 11 and 12. From figure 11 it can be seen that, within the limits of 100 iterations, the H trajectories reach the xP^*x threshold later than their corresponding L_P trajectories. In figure 12 we can see the possible implications of different configurations of L_P and ϕ; given that $xP^*X = 0.6$. As can be seen, there is a domain where neutrals are created but do not self-organize and transform into reds, and an area where they do. This phase–space diagram can be used as an instrument for generating hypotheses regarding changes in the values of L_P and/or ϕ. For example, what would happen if the city, as evolved in figure 8, were subjected to a large wave of segregative green and blue individuals. The hypothesis generated by figure 12 is that the city will move, or

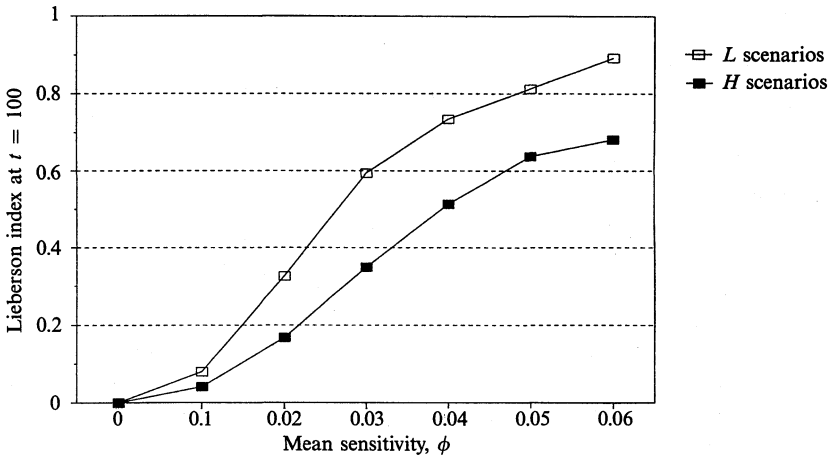

Figure 11. Variation in the Lieberson index with mean sensitivity after 100 iterations.

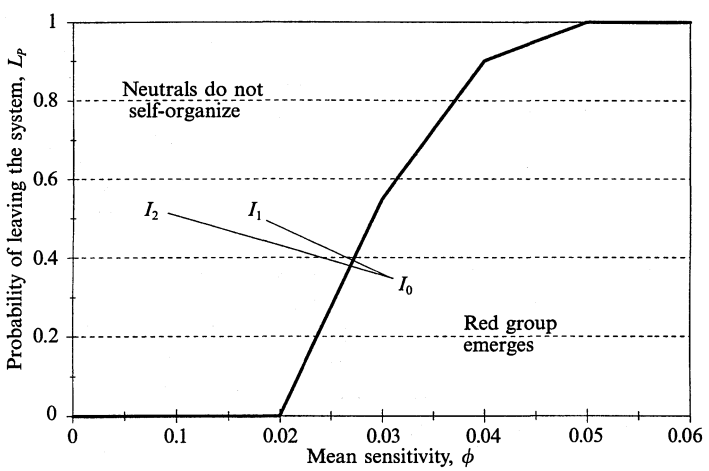

Figure 12. The domain where neutrals self-organize and transform into reds and the domain where they do not, in the phase space, of the probability of leaving the system and the mean sensitivity.

rather reverse, from position I_0 to position I_1 or I_2, depending on the number and composition of the immigrants. That is to say, the result might be the elimination of the newly created red cultural group. Given the complexity of the model and the processes it simulates, the hypothesis will have to be further investigated by experimentation with City-2. This is a task we will have to leave for a subsequent paper.

The conditions by which neutrals change their identity and become reds imply that, though cognitive dissonance alone can transform the intention of individuals, it is only in conjunction with spatial dialectics that a new sociospatial entity can emerge. This spatial dimension of the process can be observed clearly in figures 7 and 8; it can be seen that, although neutral individuals are created and distributed spatially all over the city, the process is more intense on boundaries between the homogeneous green and blue areas. The areas in between – the boundaries – are thus the most critical regions in the city for sociospatial changes (and in society at large). Similar results were obtained by Batty (1996, personal communications) in his studies on fractal cities and also in our previous studies with the model City (Portugali et al, 1994). In our studies we have

devised a graphic description (and an index) representing the city as a surface of stable and unstable cells (see figure 3). As can be seen in figure 3, the boundary areas are the most unstable regions and they are also the areas where the gap between intention and behavior is at its highest level. In fact, similar results were obtained in the present study by means of City-2, with the addition that it is in these boundary areas—the areas in between—that sociospatial bifurcation is very likely to occur and a new sociospatial entity to emerge.

Let us now compare the above discussion with the time–space evolution of the third column of maps from the left in figure 8—the (imagined) cultural identity. By comparing the third column of maps with the second, we can see that substantial areas in the city become neutral (yellow), time before the inhabitants of these areas become neutrals and then change their identity and become red. Our interpretation is that the maps in column 3 show the evolution of the collective cognitive map representing the spatiocultural image of the city. The map is collective in the sense that it is as if the city as a whole 'recognizes' these areas as potentially neutral and red. That is, in the city a house or a larger area might acquire a certain cultural identity, say red, even if the inhabitants of the house or some of the inhabitants of the area have a different cultural identity (green or blue). This is a consequence of a complex interplay between the spatial organization of the reds in relation to the other cultural groups and the city as whole. This situation characterized what happened in Adgami (the Arab quarter of Tel Aviv–Yaffo). For several years during the 1960s and 1970s this subquarter of the city was known as 'the Arab neighborhood' despite the fact that until 1976 the majority of the population in that area were Jewish and not Arab (see Portugali 1993, figure 9.2). From the locational point of view these maps can also be interpreted as representing 'expectations'. Indeed, in the empirical case of Adgami this imagined, or expected, character of the neighborhood played an important role in the locational decisions of individuals and in the subsequent evolution of the area.

We now turn, in figure 8, to the first column of maps from the left—the original cultural identity. The interesting phenomenon observed here is that, despite the changes in the sociospatial and cultural composition and configuration of the city, a blue–green sociocultural spatial segregation is maintained. It is as if the city as an entity 'remembers' and preserves the old original cultural divisions. This is, if you wish, another collective cognitive map, now representing the long-term memory of the city. The importance of this property of the city—that it preserves past sociospatial and cultural divisions—cannot be exaggerated. The recent reemergence, in the ex-USSR or Yugoslavia, of old boundaries and ethnonationalistic conflicts illustrates what has been identified above by means of City-2. That cities and regions enfold within themselves, as long-term memories, the old boundaries and past divisions and that these past sociospatial and cultural entities are potential forces which might reemerge.

The fourth column of maps in figure 8 shows how the land-value maps evolve parallel to, and in conjunction with, the evolving sociospatial surface of the city as discussed above. This is the only representative we show in this study of the economic variables included in City-2. Observing these maps we can see that the sociospatial processes of cultural identity are associated intimately with economic processes. For example, the various games or scenarios discussed above started with relatively rich blue and relatively poor green individuals. The red individuals as a new sociospatial cultural entity emerged out of a process by which blue and green segregatives turned into neutrals (yellows). As noted, this process was particularly intensive along the boundaries between the segregated blue and green areas. As can be seen in the land-value maps, this emerging new sociocultural spatial entity captures 'the area in between' also in the economic sense of the words. They become the 'middle class' between the rich blues

and the poor greens. This implies that the emerging new group have acquired not only new sociocultural spatial properties and identity, but also spatiosocioeconomic identity and status. This interplay between the spatiocultural and the spatioeconomic is interesting and we hope to be able to develop this topic further in future studies.

Conclusions

Considering the city as a self-organizing system we have shown how the dynamics of the city lead to a gap between individuals' intentions and their behavior and then to the emergence of a spatial cognitive dissonance, which in its turn leads to the emergence of a new sociocultural spatial entity. These processes and some of their properties were examined on City-2. As emphasized throughout the discussion, we have concentrated in this paper mainly on the cultural and social dimensions of the process and on their properties. In particular, the economic forces which were active in the various scenarios above or their conjunction with sociocultural processes have not as yet been examined and discussed. Furthermore, the various scenarios we have examined were stopped after 100 iterations, implying that the main focus of this paper has been on the short-term properties. Our aim in the future is to use City-2 in order to extend and complement this discussion by highlighting the full interplay between the sociocultural and economic forces operating in the city and by considering the long-term properties of this interplay.

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