Varieties of emergence

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VARIETIES OF EMERGENCE

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ABSTRACT**

The simulation of social agents has grown to be an innovative and powerful research methodology. The challenge is to develop models that are computationally precise, yet are linked closely to and are illuminating about social and behavioral theory.

The social element of social simulation models derives partly from their ability to exhibit emergent features. In this paper, we illustrate the varieties of emergence by developing Schelling's model of residential segregation (using it as a case study), considering what might be needed to take account of the effects of residential segregation on residents and others; the social recognition of spatially segregated zones; and the construction of categories of ethnicity. We conclude that while the existence of emergent phenomena is a necessary condition for models of social agents, this poses a methodological problem for those using simulation to investigate social phenomena.

INTRODUCTION

Emergence is an essential characteristic of social simulation. Indeed, without emergence, it might be argued that a simulation is not a *social* simulation. However, the notion of emergence is still not well understood (but see Sawyer 2002). In this paper, we consider the idea of emergence in a very simple way. We start with a simple model that can be applied to a wide variety of different phenomena, not just societies, but even atomic particles. We discuss how this model seems to show emergence and then suggest that to be useful as a simulation of social phenomena, the model needs to be made somewhat more complicated; and so we explore the consequences of adding several refinements. This will enable us to consider a number of different varieties of emergence. Finally, we draw some conclusions about the notion of emergence and make a methodological point.

THE SCHELLING MODEL OF RESIDENTIAL SEGREGATION

The example used here is already rather well known. Schelling (1971) published a paper in the *Journal of Mathematical Sociology* proposing a theory about the persistence of racial or ethnic segregation despite an environment of growing tolerance. He suggested that even if

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individuals tolerate[1] racial diversity, if they also remain uneasy about being a minority in the locality, segregation will *still* be the equilibrium situation.

The Schelling model consists of a grid of square patches. In the examples in this paper, the grid consists of 500×500 patches. There are 1,500 agents located on this landscape, initially at random, with no more than one on any patch. The majority of the agents, 70%, are green, and a minority are red. The remaining patches, shown in black in Figure 1, are vacant.

Each agent has a tolerance parameter. Green agents are "happy" when the ratio of greens to reds in its Moore neighborhood — the eight immediately adjacent cells or patches — is more than its tolerance. The reverse applies to the reds. So we can calculate in a straightforward way what percentage of agents are happy, given any particular configuration.

EMERGENCE OF CLUSTERS

If agents are randomly assigned to patches, an average agent has about 58%, or roughly 5 out of the 8, of its surrounding neighbors that are of its own color. In this situation, about 18%

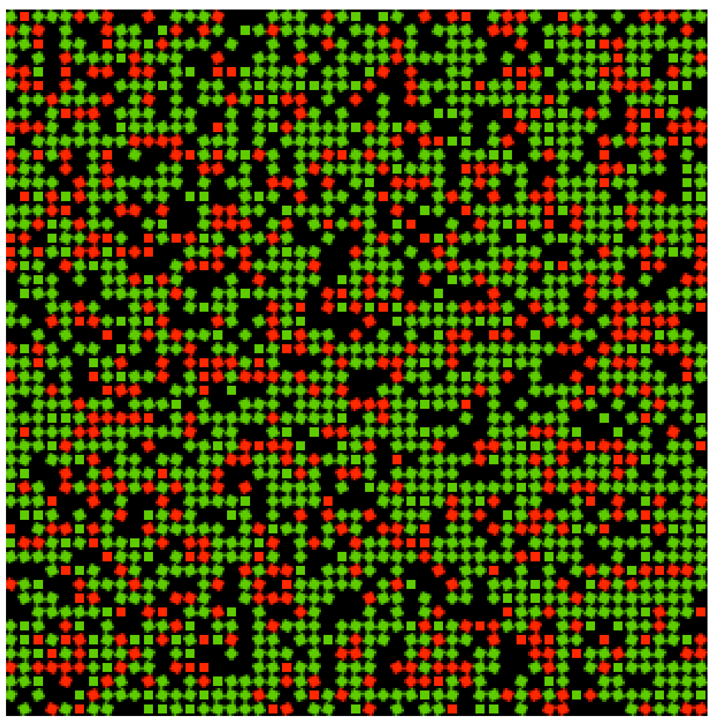

FIGURE 1 Initial Random Distribution of the 1,500 Agents: 70% Green and 30% Red

[1] The choice of the word *toleration* here is strange. We continue to use it because the literature talks about toleration. Nevertheless, we find the idea that minorities can only be 'tolerated' (rather than, for example, welcomed or celebrated) slightly repugnant.

of the agents are "unhappy." The exact percentage of unhappy agents for a particular configuration depends on the random distribution of the agents.

In this initial arrangement, there are no dynamics, no emergence, and no patterns of segregation. We just have an aggregation of cells where the number of unhappy agents can be explained analytically without much difficulty. Things get slightly more interesting when the unhappy agents are allowed to move. There are a variety of ways in which this can be implemented, the simplest being for the agent to select vacant patches at random until a congenial one is found. This can result in a phenomenon known as tipping, because when agents move to a position where they are happy, they may make other agents unhappy. These in turn will need to move, and so on.

The result is that, with moderate to low values of tolerance, the agents relocate so that they form clusters of agents all of the same color (Figure 2). The clustering, a feature of the grid as a whole, has *emerged* as a consequence of the rules obeyed by the individual agents. The extent of clustering can be measured by using statistics developed by geographers, such as the join count or Moran's contiguity ratio (Cliff and Ord, 1981; Cressie, 1991). However, we are only interested here in the fact that clustering has occurred, and this is clear from inspection of Figure 2.

Schelling showed that clustering occurs when we give the agents any value of tolerance much above 30%. As noted above, randomly allocating the agents to patches results in an average of about 58% of an agent's neighbors being of the same color. As a result of allowing the unhappy agents to move and the emergence of clusters, the percentage of same color neighbors rises to between 75% and 80%.

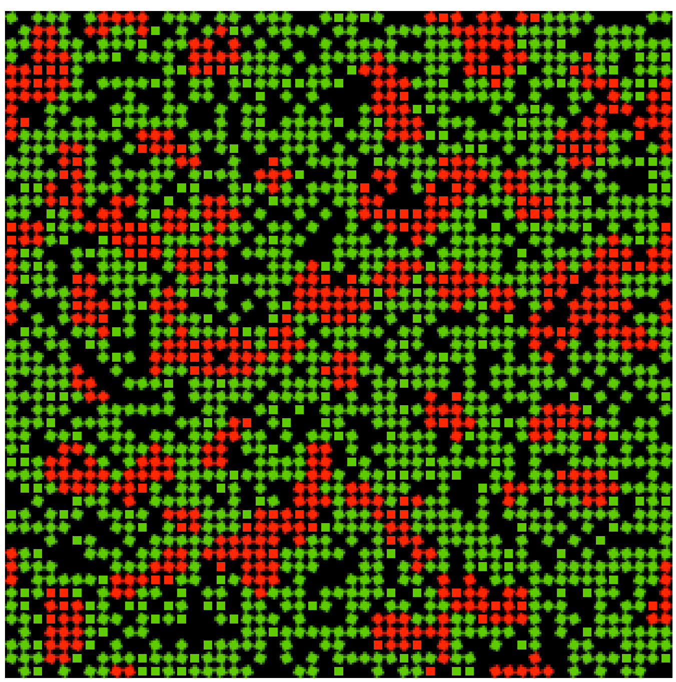

FIGURE 2 Emergence of Clustering after Unhappy Agents Have Been Allowed to Relocate by Random Walk

However, once the agents have located themselves in places where they are happy, all motion stops, giving a static, ‘frozen’ equilibrium. But that is an odd kind of model for a dynamic social world where agents are constantly on the move in some way or other. A more acceptable notion of emergence as far as social simulation is concerned is one in which emergence occurs *despite* the fact that the agents themselves are moving.

To illustrate this idea, John Holland (1975) suggests the physical analogy of the bow wave in front of a boat moving across water. Water particles constantly flow past the boat, but the bow wave itself is relatively stationary. However, few conventional definitions or descriptions of emergence insist on the need for emergent features to be maintained despite changes in the identifies of the underlying elements.

What happens in the Schelling model if the agents are constantly being replaced? Let’s repeat the simulation exactly as before, except that a random 5% of the agents are substituted by agents of random color at every time step. The clusters remain, despite the fact that after about 20 steps, most of the agents have been replaced by other individuals. Emergent social phenomena persist, even though the agents themselves may come and go.

VALIDATION

In the United States, the level of residential segregation has remained high, despite the fact that the income inequality between blacks and whites is decreasing. There are antidiscrimination laws, affirmative action policies, and generally less discriminatory attitudes by whites. The Schelling model has been used as an explanation for the persistence of residential segregation despite all these positive, progressive social policies. Although the model is usually related to racial discrimination in the United States, there are other examples of residential segregation where it could be relevant. For example, in many cities in Europe, there are districts where Chinese or Turkish restaurants are found exclusively; in Majorca, there are segregated communities of English and German immigrants, and there is religious segregation as in Northern Ireland.

There is an increasing body of scholarship that relates the Schelling model to empirical data (e.g., Clark, 1991; Portugali, et al., 1994; Portugali, 1999; Sander, et al., 2000). The recurring theme of this work is to elaborate the basic model to take more account of the implications of the fact that the agents being modeled are human and members of society. For example, the effect of what has been called ‘downward causation’, in which the emergent clusters cause changes to the behavior of the individual agents, may need to be considered.

The clusters themselves can often act as though they were agents; for example, neighborhoods can lobby city governments. Moreover, because the agents represent not particles, but people, they often recognize and name the clusters/neighborhoods, and this might have some effect on their behavior in ways that affect the development of segregation. The agents in the basic Schelling model are all exactly the same. What happens if we introduce some degree of heterogeneity? People have the ability to talk and to interact symbolically. What difference could that make? In the remainder of this paper, we explore how one might add these complications to the basic Schelling model.

DOWNWARD CAUSATION

As we have seen in the basic model, individual actions can lead to emergent features, such as clusters and neighborhoods, visible at the societal or macro level. But we should also consider the ways in which such features can influence or constrain individual action. As an example of downward causation (Campbell, 1974), let us take a typical macro-level effect: the crime rate. A crime *rate* is necessarily a macro-level attribute because it is defined as the number of crimes committed by a population per unit time. A crime rate is not a meaningful measure for individuals. Let us assume that that cost of a home in each neighborhood depends in part on the crime rate (housing is cheap in areas with high crime rates) and that the crime rate depends on the ratio of reds and greens in the locality (the more reds, the higher the crime rate). Let us also propose that, instead of choosing new locations at random, agents can only move to spots where they can afford to buy or to rent, so that they are restricted by the property value of the new location relative to the value of their old location.

Figure 3 illustrates the typical result of running such a model, and its most noticeable characteristic is that it still has clusters. The poorer reds are forced to stay in their poor red districts. The richer greens have the ability to move where they want, but they like to be around other greens in green areas. There are a very few poor greens who are surrounded by reds and who cannot move to more desirable green areas.

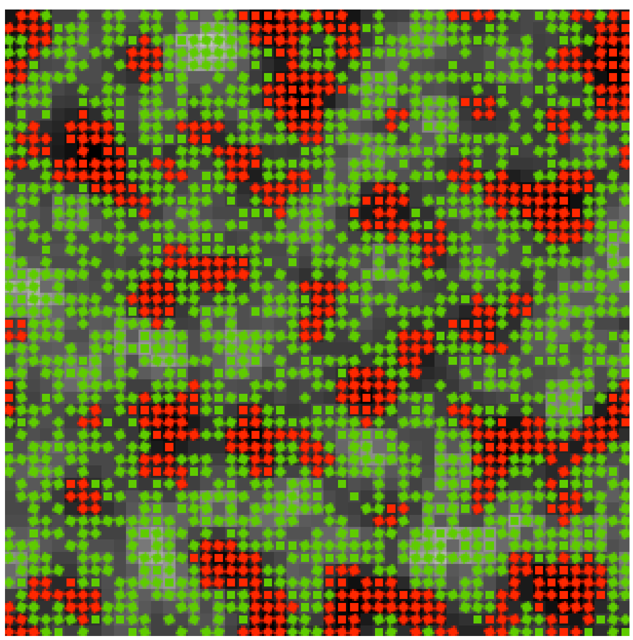

FIGURE 3 Model with Downward Causation [Background grey shade marks crime rate (black: high crime rate, low property values; white: low crime rate, high property values).]

SECOND ORDER EMERGENCE

People may recognize the neighborhoods in which they are living as having discernible boundaries, a name, and perhaps even a special history or culture. They may find the neighborhood particularly desirable for this reason (for example, fashionable neighborhoods in cities) or particularly undesirable. In other words, not only the researcher, but also agents themselves, can detect the presence of emergent features and act accordingly. And this, in turn, can affect what they do. This idea is known as second order emergence (Gilbert 1995) or the double hermeneutic (Giddens, 1986). More precisely, second order emergence occurs when the agents recognize emergent phenomena, such as societies, clubs, formal organizations, institutions, localities, and so on, where the fact that you are a member, or not a member, changes the rules of interaction between you and other agents.

We can elaborate Schelling's model in a way that illustrates what one might mean by second order emergence by allowing patches to be labeled as red or green according to their past history. The agents recognize what is a good patch for them in terms of the labels that have been applied. The analogy is with a city district that may be generally recognized to be a good or bad place to live depending partly on its current characteristics, but also partly on its history. The result is shown in Figure 4. The picture looks familiar because once again, we have clear clustering.

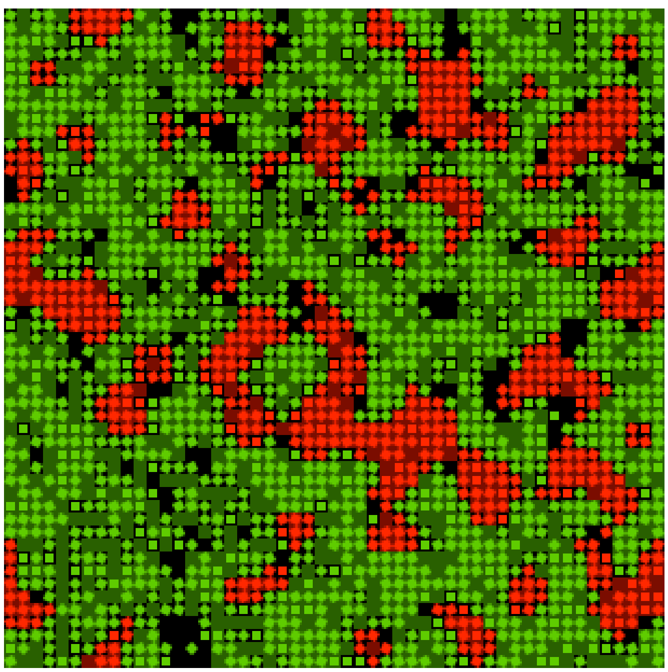

FIGURE 4 Model with Second Order Emergence [The colors of the patches (dark red or green) show the labels applied to the districts as a result of the color of the agents that were there previously or are there now.]

HETEROGENEITY

In all the models so far, the agents are identical, except for their location and color (red or green). They all have exactly the same tolerance. One can experiment with either random or systematic variations in tolerance, to correspond with environmental differences and inherited class differences.

If the tolerance for individual agents is randomly varied between agents, we get an even stronger clustering than before. If the tolerance value is arranged to correlate with the color of the agent, so that reds have a higher tolerance than greens, the reds become much more clustered than the greens (Figure 5).

How might correlations between tolerance and color arise in real populations? We might build into the model ideas of socialization, inheritance and class, and evolution or learning. However, these possibilities are not pursued here.

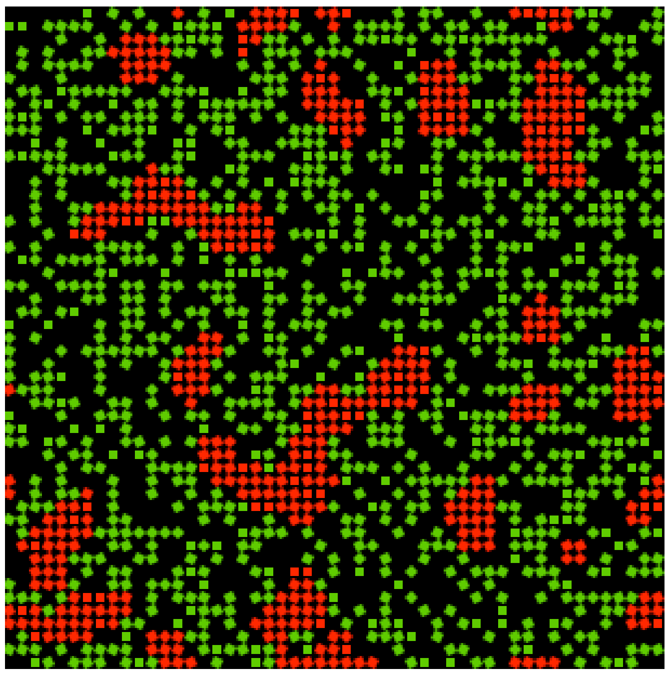

FIGURE 5 Model with Tolerance Related to Color (With tolerance at 55% for reds and 25% for greens, the reds become much more clustered than the greens.)

INTERACTION

Some of these models have depended on the idea that individual agents can conceptualize notions of neighborhood, recognize them, and communicate. But that in turn implies that we are dealing with agents that have some capacity for symbolic interaction. How might we represent this? There is a developing body of work on ‘tag models’ (e.g., Hales, 2001; Riolo, et al., 2001) in which agents have binary valued tags that can be interpreted in terms of color, ethnicity, class, education, gender, and so on. The agents act according to their tags and can also perceive the tags of other individuals.

This is rather like the Schelling model, except that instead of the modeler having chosen *a priori* that it is going to be color that marks the difference between the agents, the agents themselves decide, as it were, which of all their tags will become their significant characteristic. It could be ‘color’ or ‘gender’ or something else.

Here is a simple version. Each agent is given three binary tags. Agents are happy only if their neighbors are sufficiently similar to themselves, where similarity is measured by the Hamming distance between the agents’ tags. The outcome is again a familiar one: the agents are clustered (Figure 6). However, in this simulation, the feature shared by the agents within each cluster varies from one cluster to another. This could represent a city in which, for example, one district is ethnically black, another is united because everybody speaks Japanese, and a third is dominated by stock traders.

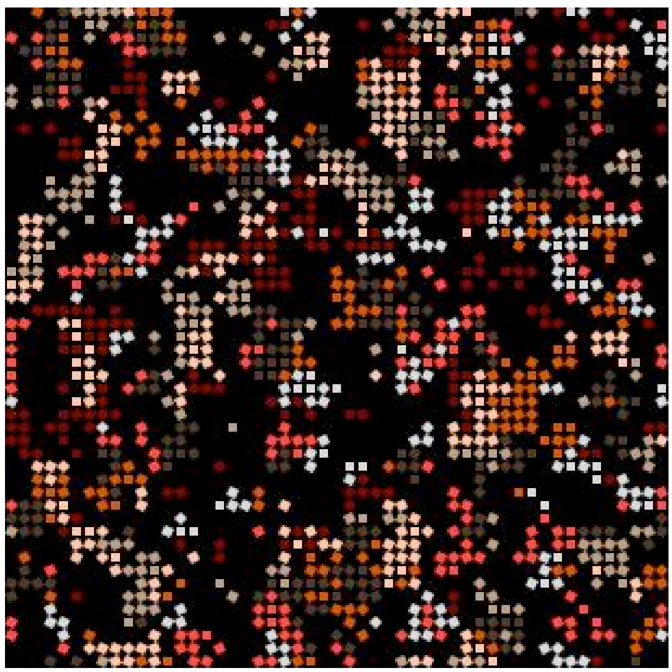

FIGURE 6 Model with Agents That Have Tags (Agents are colored according to the value of their tags, treated as a binary number.)

CONCLUSION

In this paper, we have illustrated some of the philosophical discussions about varieties of emergence, using a very simple computational model. We have tried to be straightforward about this, because there have already been some very illuminating although rather complex philosophical discussions about emergence in societies (Alexander, et al., 1987; Coleman, 1990; Archer, 1995; Sawyer, 2002). We have shown that verbal descriptions of types of emergence can be instantiated as rather simple computational models.

There is also a methodological conclusion from this exercise. All the models mentioned here seem to be adequate at some level of abstraction. Although the basic Schelling model is very simple, it did illustrate a surprising phenomenon: that 'tolerant' households could generate residential segregation through their locational decisions. We then showed that other features could be added to the model that seem to be fundamental to human societies, such as the ability to recognize emergent features. However, *all* the models yielded the same type of clusters of similar agents. The results of the simulations vary slightly in the form of the clusters and the degree of clustering, but not so much that it is plausible to conclude that one must be a better model of residential segregation than another.

The fact that we have observed emergence in all of these models cannot therefore be the sole criterion for choosing among them. The *Journal of Artificial Societies and Social Simulation,*[2] of which I am the editor, has published many papers that include an argument along the following lines: "I have developed and run a model, which shows some emergent features. The emergent features correspond to features in the real world, and since I have shown the correspondence of these features with empirical data, my model is therefore correct." A similar argument can be found in much of our social simulation literature.

We hope to have demonstrated that this kind of argument is not adequate. One has to validate a model at *both* the individual level *and* at the macro level before one can suggest that the simulation is a good representation of the social processes it is aiming to model.

ACKNOWLEDGMENTS

You may have recognized the technique of starting with a simple model and refining it, as I have done here. It was pioneered by Epstein and Axtell (1996) in *Growing Artificial Societies*, and I thank them for the idea. The models from which the figures in this paper were obtained were written in NetLogo (http://ccl.northwestern.edu/netlogo/), and I thank the developers for an excellent system.

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