Ethnic Boundary Maintenance and Historical Archaeology from an Agent-based Modeling Perspective

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Abstract

Culture contact situations result in unique trends in both the archaeological record and the long-term traditions of the cultures involved. Ethnic boundary maintenance is broadly viewed as the degree that a culture maintains its separate identity in the face of intermixing with other groups. Every situation is unique, but it has been proposed that ethnic boundary maintenance can be measured based on levels of competition, ethnocentrism, and differential power among the various groups. Agent-based modeling allows the direct observation of artificial societies comprised of different ethnicities interacting in response to the three variables above. At the individual level, inter-agent interactions drive the model to varying results dependent upon demographics and variable settings. At the group level, intermixing and patterning are differentially visible at varying parameter settings. This perspective provides measurable and comparable data useful for testing boundary maintenance in mixed ethnicity societies. The results of these simulation experiments suggest that ethnocentrism and power differential are critically bound to each other in the maintenance of ethnic boundaries.

1 Introduction

Within historical archaeology, "culture contact" is an ever-growing realm of research. It refers to situations where two or more distinct culture groups, or ethnicities, come into contact for the first time and begin the exchange of goods, information, labor, disease, etc. Ethnicity studies often focus on the way groups persist as separate entities and maintain the boundaries between them—the study of ethnic boundary maintenance (Barth 1969; Despres 1975; Lightfoot and Martinez 1995; McGuire 1982; Spicer 1971). This project intends to address ethnic boundary maintenance through three goals:

1. to test a specific ethnicity-based hypothesis with agent-based modeling,
2. to introduce agent-based modeling as a viable option for quantifying ethnic boundary maintenance, and
3. to discuss potential avenues of research using the model described here.

The hypothesis for ethnic boundary maintenance is provided by McGuire (1982:168-174), who states that:

> the theory [of ethnic boundary maintenance] is based on the examination of the relationship of three variables, competition, ethnocentrism, and differential power....the degree of ethnic boundary maintenance between two groups is primarily determined by the relations of power between them. As the differential in power equilibrates, the degree of ethnic boundary maintenance will decrease, and, conversely, as the differential in power increases, the degree of ethnic boundary maintenance will increase (McGuire 1982:174).

McGuire's focus is on the extent to which opposing groups in a culture contact situation will strive to persist, rather than be assimilated or mutually converge. Based on his explicit statement of pertinent variables, McGuire provides a clear hypothesis to test analytically.

1.1 Segregation and Thomas Schelling

Thomas Schelling (1971) devised a tipping model as a proxy for the way ethnic groups segregate in inner cities, and concluded that segregation is possible even within a population comprised entirely of un-racist people. The basic premise of Schelling's model starts with a world filled with two differently colored agents (red and blue) with tolerance levels that determine whether they are "happy" or "unhappy." Happiness is based on the percentage of agents in one's neighborhood of the same color (for example, if the percent similar is less than the agent's tolerance, the agent is "unhappy"). If "unhappy," an agent moves. If "happy," an agent remains stationary. This proceeds until all agents are "happy" with their neighborhoods. The counterintuitive result observed by Schelling is that even when agents want to be around only a minority of their own color, patchy segregation occurs, whereby the average percent of similarly-colored neighbors is much higher than the average tolerance levels.

1.2 Agent-Based Modeling and Ethnicity

The purpose of an agent-based model (ABM) is to use simulation analysis for understanding complex systems—those composed of many different parts, with the behavior of the group as a whole not simply explained by their sum (Flake 1998:229). Using ABMs as experimental tools provides a better understanding of how and when adaptations occur in the subject population (Axelrod 1997a:4). An important caveat, however, is that researchers using ABMs must fully understand the assumptions, parameters, and interaction methodologies included in each model.

Justification of Agent-Based Modeling. An ABM approach for examining ethnicity is justified for several reasons. First, the explicitly stated hypothesis from McGuire (1982:174), with a dependent variable (ethnic boundary maintenance) influenced by three independent variables (competition, ethnocentrism, and differential power), readily lends itself to analytical testing in an ABM approach due to the desire for individually-operating agents that react and interact with each other in a spatial setting. Second, the interdisciplinary nature of ethnicity—with its ties to anthropology, sociology, history, and biology—requires a modeling approach that can integrate tenets of each of these fields. ABMs provide this methodology of integration (Epstein and Axtell 1996:156-158). Third, ABMs are commonly used to study the behaviors of complex adaptive systems (see Gell-Mann 1995 and Lansing 2003). Culture contact situations involve interactions between many individuals, behaving in their own interest while revealing group level patterns such as ethnic boundary maintenance—this is self-organization (Axelrod 1997b; Epstein and Axtell 1996; Lansing 2003; Schelling 1971). Ethnicity studied within the context of an ABM can lead to further knowledge about the actual contact situations that have been under question for decades in anthropology (Deagan 1973; Herskovits 1958; Lightfoot 1995; Lightfoot and Martinez 1995; McGuire 1982; Spicer 1961; Trigg 2005). Finally, ethnicity studies are quite commonly not quantitative and are so specific that they only seem to apply to the one interaction sphere where research was conducted. For example, the St. Augustine mission project in Florida (Deagan 1973) is quality research, but lacks formal pattern comparison to other culture contact locales where similar patterns of behaviors and processes occurred.

In addition, other forms of modeling lack the ability to integrate variation at an *individual* level. ABMs provide the ability to model heterogeneous populations in which every agent may vary from every other agent in terms of its behavior, spatial location, and interaction history (Grimm and Railsback 2005:3-15). Through the use of formal modeling approaches (such as ABM), ethnicity can be studied under various situational contexts at the flip of a switch to create varying results that can be directly compared to each other as well as to empirical data observed in the archaeological record. Deterministic and nondeterministic models provide frameworks within which hypothesis testing is the main goal. Deterministic models utilize differential equations or specific processes that are applied in a top-down fashion to the data and ideas at hand. These models are repeatable and operate with the goal of attempting to make the model fail in its predicted outcome. Agent-based modeling often uses some deterministic modeling techniques, but at heart ABMs are nondeterministic, bottom-up models that incorporate stochasticity and allow for the observation of iterative, unpredictable agent interactions that provide general findings rather than the explicit failure to achieve a specified hypothesis. Nondeterministic models, like their deterministic counterparts, are also often used to test for equifinality and therefore disprove ideas that certain phenomena are the direct results of single causal events. It is generally in this arena where ABMs are most useful to nonlinear anthropological systems, and where this project attempts to build on existing research using simple nondeterministic modeling techniques (for more discussion of deterministic and nondeterministic techniques in nonlinear systems, see Premo, this volume).

Explanation of Simplified Models. This research develops methods that simplify the interactions of individuals as members of different groups, or ethnicities. The model relies solely on interactions between agents, rather than on agent-environment interactions, though this is not to imply a lack of some level of environmental influence in culture contact situations. The simplification of culture contact is justified by the hope that complex systems in the real world can be examined in a controlled arena. Researchers can "break apart" systems that are too complex to understand when fully assembled.

In addition, simplified models allow for examination of known variable interactions so that more attention can be given to variables with unknown interactions. A simple model is quite often the best model, and as such it is often best used as a tool for investigating ecological effects of human decisions (Lansing 2000:313). A simple computer model can eliminate some of the possible parameters and parameter values, using mathematical algorithms to make sense of the issues at hand (Lansing 2000:312). In this study, variability in ethnic boundary maintenance is simplified to be the result of three interacting social parameters: power, ethnocentrism, and competition. The model makes no assumptions about the effects of various geologic, climatic, or territorial limitations, except for the torus-shaped world (a geometric "donut," where the edges of the rectangular plane actually wrap around on each other). Rather, the model produces expectations of ethnic boundary maintenance that can be compared with known archaeological and historical situations of multi-ethnic interactions. Dean et al. (2000:25) state that one of the most interesting uses of models is the ability to discover the social and demographic institutions that cause real systems to differ from their simplified, modeled counterparts.

2 Methods

The model described herein was written in Objective C using the Swarm 2.2 platform, developed and maintained by the Swarm Development Group (www.swarm.org). The model was not created entirely from scratch, however. Benedikt Stefannson coded a version of Schelling's segregation model (see above; Schelling 1971) in 1997-1998 in Swarm, and Paul Johnson of the Swarm Development Group added some features and updated the segregation model in 2003. Note that this is a benefit of ABMs, whereby programmers and researchers continually borrow, verify, correct, and update previous models to fit additional research needs. The ethnic boundary maintenance model as discussed here can be downloaded for Swarm 2.2 on the web, and updated versions of the model in addition to pseudocode showing the primary model algorithms will be available as they are produced: http://www.u.arizona.edu/~bgabler.

2.1 Brief Outline of the Swarm Schelling Model

Stefansson and Johnson's agent-based version of Schelling's tipping model provides a pre-tested model of ethnocentrism, one of the key variables from McGuire's hypothesis. Additional parameters need to be implemented to represent competition and power differential, as well as modification of the program's performance to allow the population to act in a setting more similar to culture contact situations, rather than a neighborhood settlement pattern like Schelling's (1971).

However, some basic aspects of their tipping model were kept intact for the ethnicity model. The world size is default at 50x50 cells on a torus-shaped grid, with both of these parameters (size and edge-wrapping) modifiable in the parameter list at the start of each simulation run. The visibility radius of each agent is set to a distance of one cell in a Moore neighborhood (or all eight cells surrounding the agent). The scheduling of the model is asynchronous. Thus, the ethnicity model updates spatial information after each agent moves, thereby allowing each subsequent agent to adjust to the new view of the world. The default settings for demography place the starting population at approximately 50-percent blue, and 50-percent red. Additionally, a limited amount of space (20% of total cells) is left vacant at the start of each run, which means that in a 50x50 world there will be 2,000 agents and 500 empty spaces when the simulation starts.

Finally, the order in which the agents move can be randomized each time step, or it can be constant with agent number 1 as the first to move in every time step, and so on through agent number 2,000. This is modified slightly for the updated ethnic boundary maintenance model, and is discussed again later.

In Schelling's model movement is based on individual agents' internal state of happiness. Quite simply, when an agent is unhappy, it moves to a new location in order to attempt to increase its happiness. Happiness is represented as a binary value, with 0 signifying unhappiness. When an agent is surrounded by fewer similarly-colored agents than its tolerance (a preset variable that was not kept for the ethnicity model) allows, it is 'unhappy' and it moves. If an agent reaches a cell that is surrounded by a satisfactory number of similarly-colored agents, it will not move again unless that number drops below its threshold. Eventually, the model settles to an equilibrium-like state, with all agents 'happy' and therefore stationary. It is important to note this process as a strong basis for ethnocentrism, because ethnocentrism in McGuire's (1982) ethnic boundary maintenance is regarded as a population's desire to be around its own people in a culture contact situation. This definition of ethnocentrism does not imply that either population believes that it is inherently better than the other group, and the model does not attempt to account for such emotions. Overall, Schelling's tipping model provides a well-established starting point to test McGuire's hypothesis.

2.2 Ethnic Boundary Maintenance Model Parameters

In order to capture the essence of ethnic boundary maintenance as discussed by McGuire it was necessary to add several key demographic characteristics and behaviors to Schelling's model. The model was made somewhat evolutionary: agents were given the property of age and the abilities to be born, get older, reproduce, and die. Each time step, an agent grows one step older, and therefore time steps represent one 'year' if it were a real population. Agents die automatically when they reach the age of 70. These deaths make room for births, as discussed below.

Agent Characteristics and Behaviors. At the start of each simulation run (Figure 1), agents are randomly seeded across the torus, and they are given traits such as their color and age. Age is a random integer between 0 and 65, allowing all agents to survive for at least five time steps from the start of the simulation. An agent between the 'age' of 15 and 50 can select a marriage partner from its immediate neighborhood. The agent without a mate will try to find a mate with a probability of 0.5 if it is of proper age.

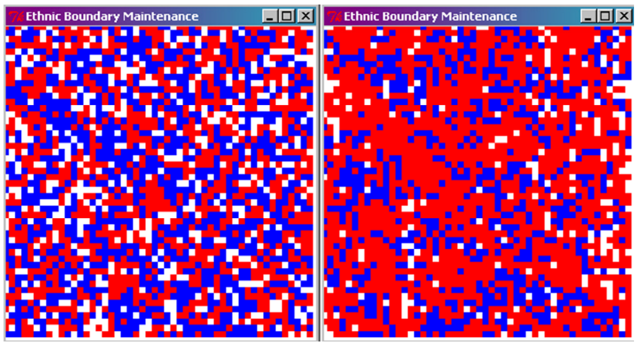

Figure 1. Ethnicity model at the start (left) and after clustering and population shift (right) of a simulation (pictured is a simulation involving differential power and ethnocentric agents (see section 3.4); light squares = high power agents, dark squares = low power agents, white squares = empty spaces).

To find a prospective mate it searches its immediate Moore neighborhood, finds another agent, then determines if this agent is the same color (no intermarriage is included in the results presented here, but the function is available in this model and will be used in future research). If the prospective mate is of the same color and does not yet have its own mate, then each adds one another to their respective mate lists and can proceed to reproduce. Each agent can have only one mate at a time, and there is no determination of biological sex in the model. It is therefore assumed that all paired agents are comprised of one male and one female, and that the overall population is divided 50/50 with reference to sex.

Once 'married,' the agents have an 11-percent (Deagan

1973) chance of reproducing each time step, calculated through random numbers just as the mating procedure—Deagan (1973) represents the populations in the St. Augustine mission, Florida, as having approximately 11-percent of the population reproduce per year, so this value is used as a known possible rate of reproduction in a historical archaeological context. Offspring are placed in a random empty cell in the immediate Moore neighborhood of the parent agent (the parent who initially called the reproduce function), and from then on move as if independent. This is for simplicity, as further rules for child-rearing would likely complicate the model beyond that which is necessary to analyze ethnic boundary maintenance. If no empty cell is found in the Moore neighborhood, the agents are not allowed to reproduce during that time step. Additionally, a pair of agents can only reproduce at a certain rate, referred to as birth limit, set as a default to every three time steps. The birth limit is simply the shortest time until a pair can attempt to reproduce again after they produce an offspring. This can also be changed at the start of each simulation from the parameter window.

The behaviors and characteristics described above relate mostly to demography, and are set at the stated values as proxies for measurement through experimentation. They are not meant to reflect actual population values due to the fact that the initial runs of the model are used to determine that the model itself functions as expected. This is discussed more at the end, but all the demography information is easily interchanged with known population values—i.e., birth rates, marriage percentages, and death rates across the entire population, instead of just at age seventy.

Competition, Power, and Movement. The remaining parameters are crucial to creating a model of McGuire's hypothesis. It has already been shown that a form of ethnocentrism is included in the original Schelling model. Therefore, only power differential and competition need to be added.

Power differential is not an objective, measurable trait that can be easily inferred from modern, let alone historic, populations. McGuire (1982) refers to differential in power and to the fact that the differential is unique in every contact situation. Therefore, a proxy for power differential was determined to be a numeric trait of each agent, ascribed at creation—or at birth for offspring—by which other aspects of their 'life' could be calculated, such as their 'happy' factor or their ability to move. Power ranges randomly among each agent from 0.6 to 0.8 for the high-power red agents and from 0.2 to 0.4 for the low-power blue agents. As with other parameters, these can be altered in the parameter window at the start of each simulation.

The measure of competition is again not an objective trait, nor is it similar in all contact situations. It makes sense to have the agents compete for some resource, and in the interest of keeping the model as simple as possible, the resource in question is physical space. Competition is generally assumed to be a method of gaining an advantage over others, and therefore the agents in a high-power group logically would have greater access to the abilities and materials in a real system. Therefore, competition in the model is operationalized by allowing all members of the high-power (red) group the ability to perform their actions first, followed by all the members of the low-power (blue) group. This fosters inter- as well as intra-group competition, because during each time step, the agents all move in the same order as the previous step. This advantage is most directly linked to reproduction because an agent attempting to reproduce has a finite chance of finding an empty cell in which to place its offspring; therefore, to move earlier in each time step is to increase one's chance of increasing one's own population.

Movement is conducted through the process of calculating 'happiness,' which could just as easily be referred to as the need to improve one's own situation. Regardless of term, the variable 'happy' is calculated as an average of: (1) the fraction of one's own color neighbors, (2) one's power, and (3) whether or not one has a mate. This algorithm varies depending on the combination of variables active in each trial, but the base formula when all active variables are on is as shown:

$$\text{happy} = \frac{\text{percent similar} + \text{power} + \text{number of mates}}{3} \qquad (1)$$

For every agent X, *percent similar* is the fraction of similarly-colored agents around agent X, *power* is the power level of agent X, and *number of mates* is 1 if agent X has a mate, 0 otherwise. The presence or absence of a mate is included in happiness because one likely goal of a population in contact situations is to reproduce, thereby increasing the population of their own kind and keeping their ethnicity slightly more intact. Happiness ranges between 0 and 1. If happiness falls below a given threshold, initially 0.6, the agent will move to a new location somewhere on the torus. Given that a step emulates an entire year's worth of time, movement is not restricted to one's local neighborhood.

Experimentation. The basis of this model is to test whether or not McGuire's (1982) hypothesis is appropriate given the described conditions, and then to determine how altering the demography, behaviors, characteristics, and hypothesis parameters affects model results.

The first three—demography, behaviors, and agent characteristics—are less critical to testing McGuire's hypothesis because the model is intended to be independent of known populations. The important aspects are those involving his hypothesized variables—competition, ethnocentrism, and power differential—and their effect on ethnic boundary maintenance. Ethnic boundary maintenance, then, is represented with a quantitative proxy called average ethnic boundary. Average ethnic boundary is calculated as the average percentage of similarly-colored agents around each individual agent. In this manner, ethnic boundary maintenance becomes the degree to which a color group can maintain its connectedness to the others in its group—maintaining identity and group ties. For example, an average ethnic boundary of 0.7 would indicate high group interconnectedness, while a value of 0.3 indicates low interconnectedness.

Each of the three key parameters can be turned on and off independently. When ethnocentrism is off, each agent no longer is affected by the percentage of similar agents around itself. When competition is off, the order in which agents move each time step is randomized; every agent has an equal chance of going first, last, and everywhere in between. When power is off, happiness is no longer affected by whether or not agents belong to the high- or low-power group. These can be turned on or off in any combination to examine the independent and combinatorial effects of each parameter.

3 Results

This section provides an overview of the results of four separate trial runs of the ethnic boundary maintenance model[1]. Each trial consisted of 20 individual simulations, lasting 405 time steps, using the same parameter settings. Each of the 20 simulations started with a different random seed, drawn by Swarm's random number generator. The same 20 random number seeds were used in each of the four trials, so that potentially different outcomes could be attributed solely to the varied parameters rather than initial conditions. The 20 simulations in each trial were averaged with respect to population and the *average ethnic boundary* for red and blue agents separately. Only *average ethnic boundaries* are graphed (Figure 2) because this is the variable in question from McGuire's (1982) hypothesis.

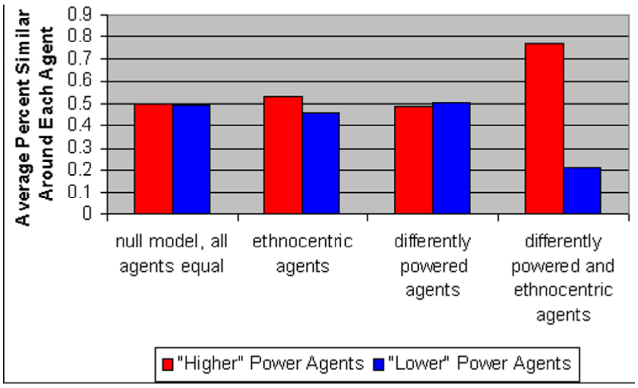

Figure 2. This graph represents the average of 20 simulation runs in each variable setting; the graphed percentage represented is that of average ethnic boundaries for each color.

3.1 Null Model

In the null model (first trial), the parameters for power, ethnocentrism, and competition are inactive. In other words, all agents are equal throughout each simulation. The only influence on happiness is the condition of mating—agents with mates are happier and therefore move less, and can reproduce. The equation, modified from (1), is:

$$\text{happy} = \text{number of mates.} \quad (2)$$

As expected and as shown in Figure 2, the average of 20 simulations suggests that there is no advantage to maintaining ethnic boundaries for either group of agents. Both groups average near 50% similarly-colored neighbors, with an equal opportunity for either group to become dominant in population number or to remain balanced in population size indefinitely.

3.2 Power Model

The second model—or power model—operates with one small variation from the null model: power differential is active. Therefore, red agents are more powerful than blue agents, altering their overall happiness and their need to continue moving to new spaces on the grid. The happiness equation for this model is:

$$\text{happy} = \frac{\text{power} + \text{number of mates}}{2} \quad (3)$$

Prior to the simulations, it was expected that the red agents would gain an advantage in this model and cause the blue agents to have a weaker *average ethnic boundary*. As is visible in Figure 2, this is clearly not the case. Again, as in the null model, there appears to be equal opportunity for either group to maintain their boundaries unaffected by the other group, and therefore the outcome of any single simulation is unpredictable.

3.3 Ethnocentrism Model

Similar to the power model, the third model—or ethnocentrism model—operates with one variation from the null model: ethnocentrism is active. In this case, individual agents are happier if they are surrounded by a higher percentage of their own color. The red agents are therefore still as likely to be unhappy as blue agents because power is not a factor. All agents move more often than in the null model because each time an agent moves, it changes the neighborhood of other agents—this was witnessed in the power model because agent movement does not influence power level. The equation for the ethnocentrism model is:

$$\text{happy} = \frac{\text{percent similar} + \text{number of mates}}{2} \quad (4)$$

Again, referring to Figure 2 reveals a trend similar to the null and power models. During the course of 20 simulations, the average percentage of similarly-colored agents is close to 50% for both groups. This result is less surprising than the results of the power model, however, because the random seed determines the starting location of agents as well as their mating and reproduction probabilities, with no internal influences on happiness, unlike the power model.

3.4 Power-and-Ethnocentrism Model

The last trial involved synchronous operation of two parameters—power and ethnocentrism. In this model, red agents have higher power than blue agents, and each agent is happier with more neighbors of its own color. The equation for this model is the same as that stated in the methods section:

$$\text{happy} = \frac{\text{percent similar} + \text{power} + \text{number of mates}}{3} \qquad (5)$$

This model produces results quite different from the other three, visually and statistically (see Figure 2). In all of the 20 simulations in this trial, the red (higher power) group dominates the blue group, in effect "choking out" the population by establishing clusters such that blue agents move more often due to unhappiness, fail to find mates, and therefore fail to reproduce. In one of the 20 simulations, the blue group completely "died" out before reaching the 405^{th} time step; in the other 19 simulations, the final blue population ranged from 1 to 23 agents, while the final red population was near 2,300 agents in each. This difference is dramatic when compared with the near equal population and boundary maintenance proportions in the other three models, where populations averaged between 1,000 and 1,200 for each group. Statistically, an ANOVA confirmed ($F = 96.648$, $p < 0.001$) that at least one of the four models' results was different from at least one of the others. The power/ethnocentrism combination model was identified by a Tukey HSD post-hoc test as significantly different from each of the other models (in each case, $p < 0.001$), and therefore the data suggest that the final model results could not have been produced at random within the range of the null or other models. None of the other models were significantly different from each other (all other $p > 0.05$).

4 Discussion

The main purpose of these experiments, as stated in the introduction, was to develop an agent-based model as a methodology to test a hypothesis. Specifically, to test McGuire's hypothesis that competition, ethnocentrism, and power differential are the critical variables causing varying degrees of ethnic boundary maintenance in contact situations, past or present. This work does not yet allow one to accept or reject McGuire's hypothesis; rather, it is suggested based on this model that ethnocentrism and power differential indeed are critical, as postulated by McGuire, and are bound to each other. It would seem as though power means nothing unless another group realizes its status as the weaker group, and dislikes it.

However, none of this undermines the hopeful outcome that shows critical necessity for quantitative approaches to ethnicity research in anthropology in general, and in archaeology specifically. Archaeologists confront material evidence and documents that are largely biased, and therefore commonly rely on developing quantitative proxies for subjective research topics; for example, understanding reasons for a shift from foraging to agriculture is difficult, but archaeologists have spent decades examining the benefits of one strategy versus another in given environmental conditions. This manuscript provides a methodology for quantifying aspects of culture contact such that comparative tests can be conducted to determine patterns in the archaeological record relating to ethnic boundaries.

Finally, it is imperative that this model is understood as a tool for conducting culture comparisons, for understanding the reasons populations maintained stances of higher power and harsh influences over other groups, such as in English colonial America or the Spanish missions, even though there is evidence that this type of behavior negatively impacted the Native populations in the New World. Agent-based models of this type allow for insights into individual behaviors that create group-level phenomena, eventually observable by us in the archaeological record as artifact, household, and settlement patterns discussed throughout this volume. Additional future research could involve the establishment of social networks to understand how the behaviors of larger social groups influence behaviors of the models and agents as a whole.

Endnotes

I do not provide any results involving competition—the competition factor is one that does not have a bearing on the outcome of the models discussed. While individual simulations yield different numbers, the actual *average ethnic boundaries* are consistent with those shown in Figure 2 whether or not competition is active.

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