Disseminating Culture

THE DISSEMINATION OF CULTURE: A MODEL WITH LOCAL CONVERGENCE AND GLOBAL POLARIZATION

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Abstract:

Despite tendencies toward convergence, differences between individuals and groups continue to exist in beliefs, attitudes, and behavior. An agent-based adaptive model reveals the effects of a mechanism of convergent social influence. The actors are placed at fixed sites. The basic premise is that the more similar an actor is to a neighbor, the more likely that that actor will adopt one of the neighbor's traits. Unlike previous models of social influence or cultural change that treat features one at a time, the proposed model takes into account the interaction between different features. The model illustrates how local convergence can generate global polarization. Simulations show that the number of stable homogeneous regions decreases with the number of features, increases with the number of alternative traits per feature, decreases with the range of interaction, and (most surprisingly) decreases when the geographic territory grows beyond a certain size.

Maintenance of Differences

If people tend to become more alike in their beliefs, attitudes, and behavior when they interact, why do not all such differences eventually disappear? Social scientists have proposed many mechanisms to answer this question. The purpose of the present essay is to explore one more mechanism. The mechanism proposed here deals with how people do indeed become more similar as they interact, but also provides an explanation of why the tendency to converge stops before it reaches completion. It therefore provides a new type of explanation of why we do not all become alike. Because the proposed mechanism can exist alongside other mechanisms, it can be regarded as complementary with older explanations, rather than necessarily competing with them.

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Unfortunately, there is no good term to describe the range of things about which people can influence each other. Although beliefs, attitudes, and behavior cover a wide range indeed, there are even more things over which interpersonal influence extends, such as language, art, technical standards, and social norms. The most generic term for the things over which people influence each other is *culture*. Therefore, the term *culture* will be used to indicate the set of individual attributes that are subject to social influence. It should be emphasized that there is no connotation that within a single society there is a uniform culture. In addition, the meaning or significance of the elements of culture is not specified. Instead, the question being investigated is how people influence each other on a given set of features, and why this influence does not lead to homogeneity.

The process by which people become similar to each other or retain their differences is central to a variety of important topics, including the following:

1. *State formation.* The formation of a national state is facilitated when its people have shared meanings and interlocking habits of communication (Deutsch 1953 and 1969). Giddens (1979) and Anderson (1991) show how nationalism is needed by the state, and the sense of imagined community is central to the attainment of nationalism. Thus, the process of at least partial convergence is critical for the formation of states.

2. *Succession conflicts.* Although states, once formed, typically seek to reduce internal cleavages, such cleavages often persist. Civil wars, especially wars of succession, tend to occur around unresolved conflicts in societies, especially when the conflicts have a clear territorial basis. Indeed, even expert observers were surprised by the extent to which lines of fracture in the Soviet Union survived decades of state efforts to ameliorate them. The process by which people become similar to each other or retain their differences is clearly vital to our understanding of how states survive or disintegrate.

3. *Transnational integration.* On a larger scale, the same processes are central to the prospects for further development of transnational institutions such as the European Community, GATT, and the United Nations. The development of international and especially transnational institutions depends in large part on the extent to which norms and ease of understanding come to be shared over territories more extensive than boundaries of current states.

4. *Domestic cleavages.* It has long been recognized that the everyday domestic politics of democracies is largely shaped by the nature of the

societal cleavages (e.g., Lipset et al. 1956; Campbell et al. 1960; Key 1961). An important question is whether such cleavages will be ameliorated or reinforced through local interactions (e.g., Coleman 1957; Putnam 1966). America's current debate over multiculturalism is just one example of our concern with the dynamics of cultural difference.

In addition to these specific topics, the effects of cultural change in the broadest sense have long been central questions. Understanding how a culture can get established, how it can spread, and how it can be sustained has growing importance in today's world. We wonder whether English will become a quasi-universal language, whether standards for new technologies can be established, and whether popular songs and dress will become universal. We applaud the spread of a common culture when it favors efficient communication, prevents unnecessary conflict, and fosters action for global needs such as sustainable growth. On the other hand, with the spread of common culture, we abhor the harm done to peoples whose cultures are destroyed, the loss to the rest of us of the wisdom embodied in these vanishing cultures, and the loss to everyone of the adaptive potential made possible by cultural diversity.

Existing explanations for why differences are durable employ a wide variety of mechanisms. They are all valid explanations under specific conditions.

1. *Social differentiation.* Groups actively differentiate themselves from each other (Simmel [1908] 1955). People who identify with one group often emphasize and even promote differences with members of other groups. In the case of ethnic groups, this differentiation can lead to sharpening of cultural and geographic boundaries between groups (Barth 1969; Hannan 1979).

2. *Fads and fashions.* When people want to be different from others, fads will come and go. When some want to be different but others want to copy them, the result is fashion: a never-ending chase of followers running after leaders.

3. *Preference for extreme views.* Tendencies toward homogeneity of opinion can be counteracted if people tend to prefer extreme positions on issues. This idea was first proposed by Abelson and Bernstein (1963). Recent simulation models have shown how this mechanism can lead to polarization and clustering (Nowak et al. 1990; Latane et al. 1994).

4. *Drift.* There may be random changes in individual traits. This can lead to differentiation among subgroups. For example, languages slowly evolve and differentiate.

5. *Geographic isolation.* If people move to be near others who are similar to themselves, the result can be clustering of similar people (e.g., Schelling 1978). If carried to extremes, geographic or other forms of voluntary or imposed segregation can sustain differences by reducing interactions between members of different groups.

6. *Specialization.* People may have interests that are at least partially resistant to social influence. This resistance has been modeled as factors that have a persistent effect on an individual despite social influence (Friedkin and Johnsen 1990; Marsden and Friedkin 1993).

7. *Changing environment or technology.* When the environment is constantly changing, the response may be constantly changing as well. If the environment is changing faster than people can respond to it, then differences may persist as different people or groups change in different ways in response to their ever-changing environment.

Despite the existence of so many mechanisms for the maintenance of differences, none of them takes into account the fundamental principle of human communication that "the transfer of ideas occurs most frequently between individuals . . . who are similar in certain attributes such as beliefs, education, social status, and the like" (Rogers 1983, 274; see also Homans 1950). The model of social influence offered here abstracts this fundamental principle to say that communication is most effective between similar people. Put another way, the likelihood that a given cultural feature will spread from one individual (or group) to another depends on how many other features they may already have in common. Similarity leads to interaction, and interaction leads to still more similarity. For reasons that will be explored below, this process need not lead to complete convergence. Indeed, the most interesting thing about the model is the way it can generate few or many distinct cultural regions depending on the scope of cultural possibilities, the range of the interactions, and the size of the geographic territory.

The present model offers a new way of looking at the dynamic process of social influence. The model is not intended to predict any particular historical events. Instead, it is meant to show the consequences of a few simple assumptions about how people (or groups) are influenced by those around them.

Approaches to Social Influence

Although over a hundred definitions of "culture" have been proposed (Kroeber and Kluckhorn 1952), everyone agrees that culture is something people learn from each other. For the present purposes, culture is assumed to satisfy two simple premises: people are more likely to interact with others who share many of their cultural attributes, and interactions between two people tend to increase the number of attributes they share. For example, a person is more likely to talk to someone who speaks a similar language than one who speaks a dissimilar language, and the very act of communication tends to make their future patterns of speech even more similar. The process of social influence applies not only to language,

but also to beliefs, attitudes, and behaviors. It applies to everything from style of dress to fundamental values, and from the adoption of Arabic numerals to the adoption of computer standards.

Anthropologists have taken two distinct approaches to the study of cultural change. The diffusionists treated a given culture as a set of distinct traits, each of which could be passed along (or diffused) to another culture (for a review, see Voget 1975). More recently, most anthropologists have emphasized the interconnections between the many traits that make up a culture, viewing culture as a system of symbols by which people confer significance on their own experience (e.g., Geertz 1973). This holistic approach stresses that the meaning of any given trait is embedded in the whole set of relationships with other traits, and consequently that a given culture tends to be a more or less integrated package. Unfortunately, neither approach has done much to formalize its ideas of cultural change in formal models whose implications can be systematically explored. (For exceptions see Renfrew 1973; Renfrew and Cooke 1979; Sabloff 1981.)

Other social scientists have provided models of how social influence works within a given society. These models of change within a single society also help illuminate how one group might influence another, and hence how one culture might influence another. An early example is Coleman's sociological model of the spread of smoking among teenage boys in which friendship affects behavior and behavior affects friendship (1965). Psychologists and sociologists have also proposed models of social influence (Nowak et al. 1990; Friedkin and Johnsen 1990; Carley 1991; Marsden and Friedkin 1993). Political scientists have built models of attitude change in political campaigns (Putnam 1966; Huckfeldt and Sprague 1991; Brown and McBurnett 1993). Organization theorists have modeled social influence in formal organizations (March 1991; Harrison and Carroll 1991). Theories about changes in beliefs, attitudes, and behavior have also been developed for the spread of social norms (e.g., Lewis 1967; Ullmann-Margalit 1977; Axelrod 1986), the spread of knowledge (Carley 1991), the diffusion of innovations (see Rogers 1983; Nelson and Winter 1982), and the establishment of technical standards (Saloner and Farrell 1986; Axelrod et al. 1995).

Finally, biologists have modeled the joint contribution of genetics and learning in social influence (Cavalli-Sforza and Feldman 1981; Lumsden and Wilson 1981; Boyd and Richerson 1985: see also Durham 1991).

A striking fact about these models is that they treat each feature of a culture independently of the other features.[1]

[1] One exception is Carley's (1991) model of the spread of knowledge. In this model, group differences disappear unless members of different groups initially share no knowledge in common. The only other exception is the "indirect bias" model of Boyd and Richerson (1985), which allows the attractiveness of a cultural trait to be affected by a control trait. But even in this model, only one cultural trait is considered.

The model of social influence given in this essay is new in two regards. First, it explicitly takes into account that the effect of one cultural feature depends on the presence or absence of other cultural features. Second, it takes into account that similar individuals are more likely to influence each other than dissimilar individuals. The only other formal model that treats culture as multidimensional does not take into account the degree of cultural similarity in its mechanism for social influence (Epstein and Axtell, 1996).[2]

The methodology of the present study is based on three principles:

1. *Agent-based modeling.* Mechanisms of change are specified for local actors, and then the consequences of these mechanisms are examined to discover the emergent properties of the system when many actors interact.[3] Computer simulation is especially helpful for this bottom-up approach, but its use predates the availability of personal computers (e.g., Schelling 1978).

2. *No central authority.* Consistent with the agent-based approach is the lack of any central coordinating agent in the model. It is certainly true that important aspects of cultures sometimes come to be standardized, canonized, and disseminated by powerful authorities such as church fathers, Webster, and Napoleon. The present model, however, deals with the process of social influence before (or alongside of) the actions of such authorities. It seeks to understand just how much of cultural emergence and stability can be explained without resort to the coordinating influence of centralized authority.

3. *Adaptive rather than rational agents.* The individuals are assumed to follow simple rules about giving and receiving influence. These rules are not necessarily derivable from any principles of rational calculation based upon costs and benefits, or forward-looking strategic analysis typical of game theory. Instead, the agents simply adapt to their environment.

The Model

Culture is taken to be what social influence influences. For present purposes, the emphasis is not on the content of a specific culture, but rather

[2] The Epstein and Axtell "Sugarscape" model is very rich, incorporating trade, migration, combat, disease, and mating. For example, actors of similar culture are allowed to mate, and actors of dissimilar culture are allowed to fight.

[3] Agent-based models in political science have usually focused on conflict processes (such as war and military alliances) rather than social influence. Examples are Bremer and Mihalka (1977), Schrodt (1981), Cusack and Stoll (1990), Axelrod (1995), and Cederman (forthcoming). Agent-based models dealing with social influence are Huckfeldt and Sprague (1991) and Brown and McBurnett (1993). A wide-ranging agent model is Epstein and Axtell (1996).

on the way in which any culture is likely to emerge and spread. Thus, the model assumes that an individual's culture can be described in terms of his or her attributes, such as language, religion, technology, style of dress, and so forth.

Because the model can be abstract about the specific content of an individual's culture, it describes a culture as a list of *features* or dimensions of culture. For each feature there is a set of *traits*, which are the alternative values the feature may have. For example, one feature of a culture could be the color of belt that is worn, and the traits would be the various alternative colors that might be worn in a society. To be concrete, suppose that there are five features and each feature can take on any one of ten traits. Then a culture can be described as a list of five digits such as 8, 7, 2, 5, and 4. In this case, the first cultural feature has the eighth of its possible values. This abstract formulation means that two individuals have the same culture if they have the same traits for each of the five features. The formulation allows one to define the degree of cultural similarity between two individuals as the percentage of their features that have the identical trait.

The model includes a geographic distribution of individual agents. A simple example would be a set of 100 sites, arrayed on a ten by ten grid. Because there is no movement in the model, the sites themselves can be thought of as homogeneous villages. These sites are the basic actors of the model. Each site can interact only with its immediate neighbors. A typical site has four neighbors (north, east, south, and west). Sites on the edge of the map have only three neighbors, and sites in the corners have only two neighbors.

Table 7-1 shows a typical starting situation with randomly assigned cultures. As expected, most of the sites share no more than one feature with any of its neighbors. The underlined site, however, happens to share two features (the fourth and the fifth features) with its neighbor to the south. Because these two sites share two of the five attributes, their cultural similarity is 40 percent.

The process of social influence in the model can be described as a series of events. The basic idea is that agents who are similar to each other are likely to interact and then become even more similar. This is implemented by assuming that the chance of interaction is proportional to the cultural similarity two neighbors already have. Here, then, is the formal statement of the entire dynamics of the model:

Repeat the following steps for as many events as desired.

Step 1. At random, pick a site to be active, and pick one of its neighbors.

Step 2. With probability equal to their cultural similarity, these two sites interact. An interaction consists of selecting at random a feature on which the active site and its neighbor differ (if there is one), and changing the active site's trait on this feature to the neighbor's trait on this feature.[4]

TABLE 7-1
A Typical Initial Set of Cultures

74741	87254	82330	17993	22978	82762	87476	26757	99313	32009
01948	09234	67730	89130	34210	85403	69411	81677	06789	24042
49447	46012	42628	86636	27405	39747	97450	71833	07192	87426
22781	85541	51585	84468	18122	60094	71819	51912	32095	11318
09581	89800	72031	19856	08071	97744	42533	33723	24659	03847
56352	34490	48416	55455	88600	78295	69896	96775	86714	02932
46238	38032	34235	45602	39891	84866	38456	78008	27136	50153
88136	21593	77404	17043	39238	81454	29464	74576	41924	43987
35682	19232	80173	81447	22884	58260	53436	13623	05729	43378
57816	55285	66329	30462	36729	13341	43986	45578	64585	47330

Note: The underlined site and the site to its south share traits for two of the five cultural features, making a cultural similarity of 40 percent.

This process can be illustrated using Table 7-1. In step 1, suppose the underlined site is selected, along with its neighbor to the south. In step 2, the active site and its neighbor have a 40 percent chance of interacting because they share traits for two of their five features. If they do interact, then the culture of the underlined site would take on the trait of one of the three features that was different in the culture of its neighbor to the south. For example, if the first feature was the one to change, then the value of 6 from the neighbor's first feature would become the value of the first feature of the underlined site, changing its culture from 82330 to 62330. This change will increase the cultural similarity of these two sites from 40 percent to 60 percent, making it even easier for them to converge still further.[5]

Note that the activated site, rather than its neighbor, is the one that may undergo change. This is done to guarantee that each site has an equal chance of being a candidate for social influence, even though the sites on the edge of the map have fewer neighbors than sites in the interior.

[4] For those who prefer symbolic statements, here is a complete description of how the culture, c, at a site can change. Select a random site (s), a random neighbor of that site (n), and a random feature (f). Let $G(s,n)$ be the set of features, g, such that the cultural traits are unequal, i.e. $c(s,g) \neq c(n,g)$. If $c(s,f) = c(n,f)$ and G is not empty, then select a random feature, g, in $G(s,n)$, and set $c(s,g)$ to $c(n,g)$. This implementation of the model takes advantage of the fact that the probability that a random feature, f, will have the same trait at two sites equals the cultural similarity between those two sites.

[5] The simulation is done one event at a time to avoid any artifacts of synchronous activation of the sites. See Huberman and Glance (1993).

The Emergence of Regions of Shared Culture

How do cultural regions develop? Does everyone come to share the same culture, or do distinct cultural regions develop? Does the system settle down, and if so, how long does it take?

To begin to answer questions like these, it pays to start with a single run of the model over time.[6] To make the development of cultural regions more apparent, we can shift our attention from the details of the culture at each site to the cultural similarities between adjacent sites. These cultural similarities can be represented in a map, such as the one in Figure 7-1(a). This shows the (cultural) distances between adjacent sites at the start. Notice that most of the boundaries are drawn in black, indicating that at most one of the five features is shared. The site marked "A" in Figure 7-1(a) corresponds to the underlined site in Table 7-1. Notice that the boundary between this site and the one to its south is drawn in dark gray, indicating that the cultural similarity between them is 40 percent at the start of the run.

The other panels of Figure 7-1 show what happens over time.[7] Time is measured in events, representing the activation of a site. For example, Figure 7-1(b) shows the start of the emergence of distinct cultural regions after 20,000 events. For our purposes, a *cultural region* can be defined as a set of contiguous sites with the identical culture. Notice that already at this stage, many cultural boundaries have disappeared as some cultural regions have grown to include four or five sites.

By 40,000 events the cultural regions have gotten bigger. In addition, even many of the boundaries between regions are now light gray, indicating that there is only a single feature on which they differ. By 80,000 events, there are only four regions left. In fact, by 81,000 events, the region surrounded by light gray gets completely absorbed into the largest region, leaving only three regions. Not only that, but the remaining three regions are completely stable because members of adjacent regions have absolutely no features in common and hence cannot interact.

Some of the questions can now be answered about the effects of social influence over time and space in this model.

[6] The model can be regarded as a Markov process with absorbing states. Unfortunately, the mathematical tools for analyzing Markov processes, such as eigenvalue analysis, are not very helpful in this case because the dynamics are so complex. For example, the number of possible states for the situation given in Table 7-1 is 10^{500}, which is far more than the number of atoms in the universe. Other agent-based models that can be regarded as Markov processes have also had to resort to computer simulation (e.g., Bremer and Mihalka 1977; Schrodt 1981; and Cusack and Stoll 1990).

[7] The model is coded in Pascal. Running on a Macintosh Quadra 700, the run shown in Figure 7-1 took eleven seconds. See fn. 12 for source code availability.

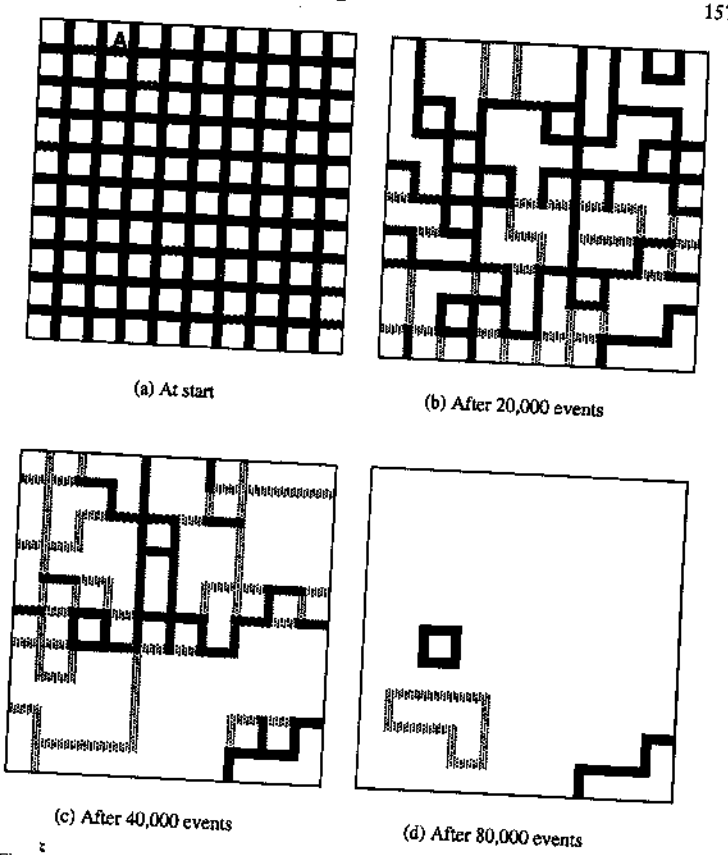

Figure 7-1. Map of Cultural Similarities. *Note:* Cultural similarity between adjacent sites is coded as: Black ≤ 20%, Dark Gray = 40%, Gray = 60, Light Gray = 80%, White = 100%. This run was conducted using five cultural features and ten traits per feature, using the initial conditions shown in Table 7-1. Each interior site has four neighbors.

1. Initially, most neighboring sites have little in common with each other, and hence are unlikely to interact. However, when two sites *do* interact they become more similar, and hence are more likely to interact in the future.
2. Over time, specific cultural features tend to be shared over a larger and larger area. Indeed, regions start to form in which *all* the features are exactly the same.

3. Eventually, no further change is possible. This happens when every pair of neighboring sites have cultures that are either identical or completely different. If a pair are identical, they can interact but the interaction will not cause either to change. If they are completely different, they will not even interact. In the sample run shown in Figure 7-1, the process settled down with exactly three cultural regions, two of which had few sites.

4. Initially, there are almost as many regions as sites, but eventually there are only a few regions. An indication of the extent to which the process of social influence resists complete homogenization is the number of regions that remain when no further change is possible. The number of *stable regions* can be defined as the number of cultural regions that exist when each cultural region has nothing in common with any of the regions it is adjacent to. In the sample run, shortly after the time shown in Figure 7-1(d), exactly three stable regions survived, two of which had few sites.

5. In retrospect, the origins of the stable cultural regions can be seen far back in history.[8] For example, the cultural region of four sites in the southeast corner of Figure 7-1(d) can be clearly discerned as far back in time as Figure 7-1(b). However, looking just at the map of cultural similarities at that early time would not allow one to know which of the many cultural regions that existed then would survive.

The Number of Stable Regions

For society, an important question is how many cultural regions will survive. Although all social influence in the model involves convergence between neighbors, the process of convergence can stop with several surviving cultural regions, each of which is completely different from the adjacent cultural regions.

In the sample run, three cultural regions survived. This is fairly typical of runs done under identical conditions but with different random choices. In a set of 100 runs of this type, the median number of stable regions was three. But there was also quite a bit of variation. In 14 percent of the runs there was only one stable region, while in 10 percent of the runs there were more than six.

Scope of Cultural Possibilities

The model can be used to explore how the number of stable regions depends on various factors such as the scope of cultural possibilities, the range of the interactions, and the size of the geographic territory. First

[8] This is an example of what is called path dependence (e.g., Arthur 1988).

consider the scope of cultural possibilities. In the model, cultural complexity depends on two things: the number of cultural features and the number of possible traits that each feature can have. For example, in the sample run there were five features, each with ten possible traits. A plausible hypothesis is that the more variety that is possible among cultures, the greater the number of stable regions there will be. This hypothesis would be based on the idea that the more features and the more traits per feature, the more cultural regions there would be at the end.

Table 7-2 shows the average number of regions that resulted from all combinations of five, ten, or fifteen features as well as five, ten, or fifteen traits per feature. For each combination of parameters, ten runs were conducted. Table 7-2 shows that the original culture of five features of ten traits each gave an average of 3.2 stable regions.

When the number of traits per feature was held at ten, but the number of features was increased from five to ten or fifteen cultural features, the process converged to a single stable region. Thus, as the number of features grows, so does the likelihood of complete cultural convergence. This seems counterintuitive at first, because one might suppose that more features would make convergence more difficult. In fact, just the opposite is true. The reason is that with more features, there is a greater chance that two sites will have the same trait on at least one feature, and therefore will be able to interact. With interaction comes the sharing of the trait on an additional cultural feature. So with more features in the culture there is a greater chance neighbors will have something in common, and thus they will have a greater chance to attain complete cultural convergence with each other.

The effect of differing the number of traits on each feature is also shown in Table 7-2. Again there is a curious result: increasing the number of traits per feature has the opposite effect of increasing the number of features. For example, moving from ten to fifteen traits when there are five features actually increases the average number of stable regions from 3.2 to 20.0. When there are few features and many traits then there is a good chance that two neighbors will share no features, and thus be unable to interact. This in turn makes it easier for many distinct regions to form, each of which has no features in common with any adjacent region.

In sum, the complexity of the culture needs to be differentiated to account for the number of stable regions. Having more features (i.e., dimensions) in the culture actually makes for fewer stable regions, but having more alternatives on each feature makes for more stable regions.

Range of Interaction

The next question is how the process of cultural formation is influenced by the number of neighbors with which a site can interact. So far, each

TABLE 7-2
Average Number of Stable Regions

Number of cultural features	Traits per feature		
	5	10	15
5	1.0	3.2	20.0
10	1.0	1.0	1.4
15	1.0	1.0	1.2

Note: These runs were done with a territory of 10 × 10 sites, and each interior site had four neighbors. Each condition was run ten times.

interior site was allowed to interact with four adjacent sites. It is plausible that if interactions could occur over somewhat greater distances, the process of cultural convergence would be made easier. The expected result would be fewer distinct regions when the process settled down.

To test this hypothesis, additional runs were conducted in which each site could interact with other sites using larger neighborhoods, encompassing eight and twelve neighbors for interior sites. The neighborhoods with eight sites consisted of the four adjacent sites plus the four diagonal sites, making a square neighborhood. The neighborhoods of twelve sites consisted of those eight sites plus the four sites that were two units in each of the cardinal directions, making a diamond shaped neighborhood. To study the effect of neighborhood size, the entire set of ten replications of each of the nine kinds of culture was run for the neighborhood of sizes of four, eight, and twelve.

As expected, larger neighborhoods result in fewer stable regions. Averaged over the nine types of culture, small neighborhoods have 3.4 stable regions, medium-sized neighborhoods give 2.5 stable regions, and large neighborhoods generate only 1.5 stable regions. Thus when interactions can occur at greater distances, cultural convergence is easier.

Size of the Territory

The final statistical question is how the outcome of social influence process is affected by the size of the territory. In all the runs so far, the size of the territory was 10 × 10 sites. Over the nine different kinds of culture and three different sizes of neighborhoods, there was an average of 2.5 stable regions. One would suppose that the more sites there are, the more cultural regions result.

To test this hypothesis, additional territories were examined that were

5 × 5 sites, and 15 × 15 sites. A complete factorial design was done for each of the eighty-one conditions: three sizes of territory, nine types of culture, and three types of neighborhood. Each condition was replicated ten times, giving 810 runs in all. The results are very surprising. In these runs, the size of the territory had no substantial effect on the number of cultural regions formed. Here are the averages: with small (5 × 5) territories there were 2.4 stable regions, with medium (10 × 10) territories there were 2.5 stable regions, and with larger territories (15 × 15) there were 2.2 stable regions.

Clearly, a more detailed analysis of the effect of size is needed. The best way to do this is to hold the other parameters constant. For convenience, the other parameters can be fixed at the levels that gave the largest number of stable regions. This means few cultural features (five), many traits per feature (fifteen), and small neighborhoods (four neighbors for interior sites). With these parameters held constant, the number of stable regions can be determined as a function of the size of the territory.

The results are shown in Figure 7-2, which summarizes forty runs each for territories from 2 × 2 sites up to 35 × 35 sites, and ten runs each for territories of 50 × 50 and 100 × 100 sites. Consistent with the earlier runs shown in Table 7-2 (with few features and many traits per feature), there were about twenty stable regions in a territory of 10 × 10 sites. The overall result shown in Figure 7-2 is that the number of stable regions increases until it reaches a maximum of about twenty-three when the territory has 12 × 12 sites. The number of stable regions then declines to about six for a territory of 50 × 50 sites and about two for a territory of 100 × 100 sites.

The earlier result suggesting that territorial size did not have a substantial effect on the number of stable regions can now be seen as misleading. The earlier analysis averaged nine kinds of culture and three ranges of interaction, leading to about the same number of stable regions no matter whether the territory was 5 × 5, 10 × 10, or 15 × 15. The results shown in Figure 7-2, however, demonstrate that when the type of culture and the range of interaction is held constant, the number of stable regions is very sensitive to the size of the territory: both small and large territories have few stable regions, whereas moderate-sized territories have the largest number of stable territories.

Why do moderate-sized territories have the largest number of stable territories? It is no surprise that smallest territories have the fewest stable regions. After all, small territories simply do not have enough sites to contain many different cultures. So it is not surprising that as the size of the territory increases from, say, 2 × 2 sites to 12 × 12 sites, the number of stable regions increases. What is really surprising is that as the size of the territory increases further, the number of stable regions actually de-

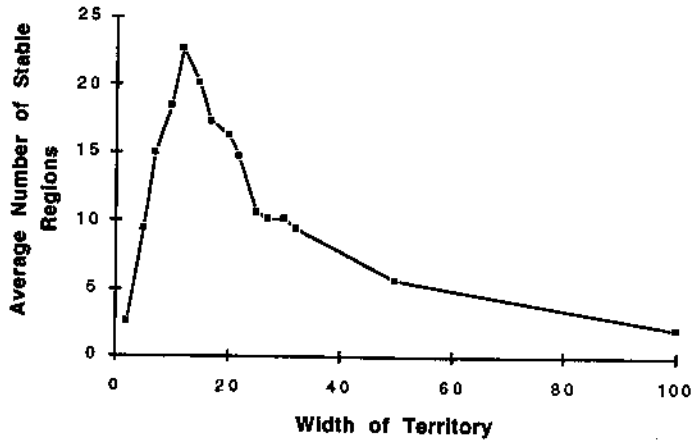

Figure 7-2. Average Number of Stable Regions. *Note:* The parameters for these runs are five cultural features, fifteen traits per feature, and four neighbors for interior sites. Each territory size was replicated forty times, except the territories with 50 × 50 sites and 100 × 100 sites, which were replicated ten times.

creases. So the interesting question is: why do large territories have fewer stable regions than moderate-sized territories?

The result is so surprising that one might wonder whether it is due to a programming error. Fortunately, this explanation can be ruled out. The present simulation model has been independently implemented by another team in what is apparently the first systematic effort to align two related agent-based simulation systems (Axtell et al. 1996). The key results of the present model were confirmed.

One might also wonder whether the phenomenon of large territories having fewer stable regions has something to do with the existence of boundaries on the territories. Boundaries can be eliminated by wrapping around the northern and southern edges, and the eastern and western edges. Simulations with this neighborhood topology show the same pattern as before: the number of stable regions increases for a while as the size of the territory increases, but then declines. Although the peak occurs earlier (i.e., with somewhat smaller territories) and is not as high (i.e., with somewhat fewer stable regions), the shape of the curve is similar to the one in Figure 7-2. So the existence of territorial boundaries is not the cause of large territories having fewer stable regions than moderate-sized territories.

To see why larger territories have fewer stable regions, it is useful to examine what happens over time in runs of various sizes.

Analysis of Histories

Dialects

To understand the historical development of social influence in this model, it pays to examine an artificially constructed illustration where there are just two cultural regions, differing in a single feature. I use the term "dialects" to describe two such similar cultures. To keep things really elementary, suppose there are just six sites on a line from west to east, and the neighbors of each site are the adjacent sites. (See Table 7-3.)Suppose, further, that the four on the west have the same culture, namely 11111, whereas the two sites on the east have culture 11112. If the activated site and its selected neighbor are both within the same region, no change would occur, because there would be no cultural difference to transmit. Thus, the only possibility for change would be if the active site was in one region and its selected neighbor was in the other. The consequence would be that the boundary between the two regions would move by one site, either to the east or to the west. Moreover, these two possibilities are equally likely. The next time a social influence takes place, the regional boundary will move again, and once again there is an equal chance the boundary will move to the east as to the west. The movement of the regional boundary follows a process known as a random walk with absorbing barriers (e.g., Kemeny et al. 1966, 283). In this illustration, stability will be reached when the boundary between the regions moves all the way to the east or to the west, that is, when one dialect has completely "eaten" the other dialect.

An interesting thing about this illustration is that the larger region is more likely to "eat" the smaller region than the other way around. The reason is that the random walk of the boundary is more likely to reach the nearer edge of the map before it reaches the further edge. Thus, the majority culture is more likely to survive than the minority culture, even though there is absolutely no bias in the process of social influence. This brings to mind the effort at universities and elsewhere to protect the diversity of a multicultural society.

This result that large regions tend to "eat" small regions can help explain what happened toward the end of the run shown in Figure 7-1. Recall that after 80,000 events there were four regions, one of which differed from the largest region in a single cultural feature (see Figure 7-1(d)). Once history got to this stage, the small dialect with just four

TABLE 7-3
An Illustration of Social Influence between Dialects

a. Suppose there are two regions in a territory of 6x1 sites. Suppose the regions are dialects, differing in a single feature. Suppose one region has four sites while the other region has two sites:

11111 11111 11111 11111 11112 11112

b. Since most sites are identical to all of their neighbors, there are only two possibilities for social influence. These two possibilities are equally likely:

i. The fourth site is activated and borrows from the fifth site, moving the regional boundary to the west.

11111 11111 11111 11112 11112 11112

ii. The fifth site is activated and borrows from the fourth site, moving the regional boundary to the east.

11111 11111 11111 11111 11111 11112

c. Eventually, the process will stop when one dialect or the other is eliminated. More likely, the 11111 dialect will eliminate the 11112 dialect because it started with more sites.

sites was much more likely to become extinct than the large dialect, which has ninety-one sites. Notice that as long as the sites in the other two small regions had nothing in common with any of their neighbors, they would not change. The possibility for social influence ended when the larger dialect "ate" the smaller dialect, resulting in just three stable regions.

The idea of dialects of similar cultures leads to the idea of cultural zones of similar regions. This in turn can help unravel the puzzle of why large territories have few stable regions.

Cultural Zones

Recall that a cultural region is a set of contiguous sites with identical cultures. A related idea is a *cultural zone:* a set of contiguous sites each of which has a neighbor with a "compatible" culture. Cultures are compatible if they have at least one feature in common. This means that neighboring sites with compatible cultures can interact. Thus, although the sites in a single cultural zone may include many different regions, each of

the regions in a zone is able to interact with adjacent regions in the same zone.[9]

To see how zonal and regional boundaries develop over time in a relatively small territory, let us return to the run illustrated in Figure 7-1. In Figure 7-1(d) there are four regions. However, there are only three zones, as indicated by the black boundaries between adjacent sites, that have no features in common. The run ends when no further change is possible, and this happens when each zone has exactly one region, since that implies that sites in different regions can no longer interact. In the run shown in Figure 7-1, stability was reached when the small dialect was "eaten" by the largest region. The resulting three regions correspond exactly to the three zones of Figure 7-1(d). Going back in history to Figure 7-1(c), there were dozens of regions but exactly the same three zones. In fact, this is a common historical pattern, with the zones developing before the regions. Thus the number of zones provides an early indication of just how many stable regions there will be.

Figure 7-3 shows how the number of regions and zones develop over time in a single run with a very large (100 × 100) territory with 10,000 sites.[10] Initially, the number of regions is virtually the same as the number of sites because it is very unlikely that two adjacent sites will have each of their five features be equal when there are fifteen possible traits for each feature. However, even at the start there are fewer zones than regions because many sites will have at least one feature in common with at least one neighbor. As Figure 7-3 shows, the number of regions declines gradually until there are about a thousand regions, and then declines in stages until there are only two regions. On the other hand, the number of zones declines quickly to just two. As mentioned above, when the number of regions equals the number of zones, no further change is possible. It is striking that it takes more than four times as long for the stable regions to be determined than for the final number of zones to form. So most of the history of the run was spent with many compatible cultures "struggling for survival" within just two cultural zones, until finally only a single culture survived in each zone. Because one of the final two zones has only one site, all of this "struggle" took place over the 9,999 sites of the other final zone.

[9] Technically, two sites are in the same zone if there is a path of adjacent sites from one to the other such that each site has at least one feature in common with the next one on the path.

[10] Note that for Figure 7-3, the parameters were chosen to generate relatively large numbers of stable regions. With these parameters, the average number of stable regions in 10 × 10 territories was about 18.6, whereas in 100 × 100 territories, the average was only 2.1. (See Figure 2. The slight discrepancy for the number of stable regions in the 10 × 10 territory in Figure 7-2 compared to the corresponding cell in Table 7-1 is due to averaging over different runs.)

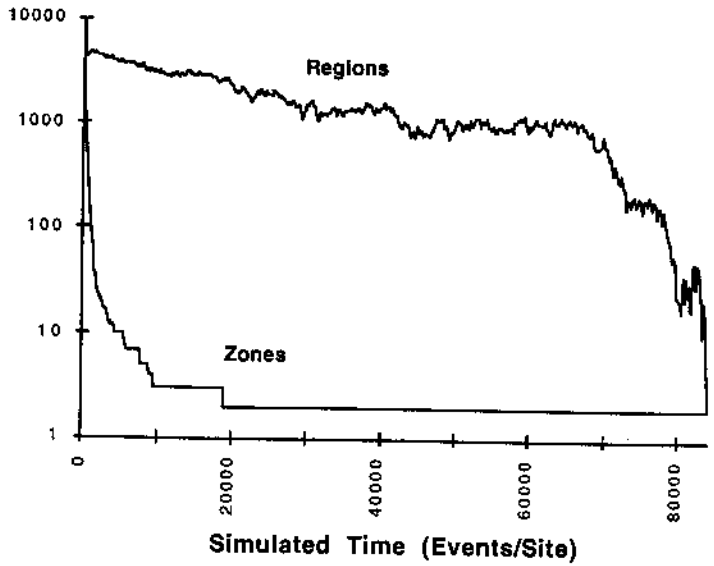

Figure 7-3. Number of Cultural Regions and Cultural Zones over Time in a Run with a Large Territory. *Note:* The territory is 100 × 100 sites. The other parameters are as in Figure 7-2. Note logarithmic scale.

Dissolution of Cultural Boundaries

Over time, boundaries between regions in the same cultural zone tend to dissolve. For example, if two adjacent sites share three of their five cultural features, there is a good chance that they will interact and then share four features. Then they may interact again and come to share all five of their features. Of course, things are more complex than this because either of the two sites might also interact with others, and this might actually decrease the cultural similarity between them. But on average, cultural similarity between adjacent sites in the same cultural zone tends to increase.

On the other hand, adjacent sites in different cultural zones cannot interact because they have no cultural features in common. This is why boundaries within cultural zones tend to dissolve, but boundaries between cultural zones tend to be stable. Nevertheless, even boundaries between cultural zones can dissolve. A boundary between two cultural zones can dissolve if a site on the zonal boundary adopts a trait for a

feature from another region in its zone. If this newly adopted trait happens to match the corresponding feature of a neighboring site from the other zone, then the zonal boundary will begin to dissolve. This accounts for how the number of cultural zones decreases over time, as shown in Figure 7-3.

Another way of looking at the dynamic process is to consider how alternative traits for a cultural feature move around in a zone as neighboring sites interact. As long as there are many regions within each zone, there are different cultural traits for at least some of the features in the zone. As these traits move around in the zone through interactions, they have a chance of dissolving boundaries, both regional and zonal. The net effect is that the more time it takes for a territory to settle down, the more chance there is that zonal as well as regional boundaries will be dissolved.

Large territories take much longer to reach stability than smaller territories, and this gives the regional and even zonal boundaries in large territories more opportunities to dissolve. This is true even though in comparing territories of different sizes, simulated time should be measured in events per site rather than simply events. The reason why time is measured in events per site is that in reality various sites might be active at virtually the same time.

Just how does time to stability vary as a function of territorial size? Over a great range of territories, from four to 10,000 sites, the time to stability is almost exactly proportional to the number of sites in the territory. For example, with 1,024 sites (in a 32 × 32 territory), each site needs an average of 10,036 events to reach stability. When there are about 2.5 times as many sites (in a 50 × 50 territory), about 2.5 times as many events per site are needed to reach stability (or 25,900 events). As the number of sites doubles, each site has twice as many chances to be active before stability. Therefore, doubling the number of sites in a territory allows four times as many activations in all. This in turn provides many more opportunities for boundaries to dissolve, eventually reducing the number of regions that will still exist when no further change is possible. (By the way, to do a run of a 100 × 100 territory, each site needs a little over 100,000 events before stability is reached. Because there are 10,000 sites, a single run of this size requires simulating a billion events.)

In sum, combining an analysis of dialects, cultural zones, and the dissolution of cultural boundaries helps explain how territorial size determine the number of stable regions. In small territories there is not much room for many stable regions. In moderate-sized territories there is enough room. In large territories, there is even more room, but the process of social influence and the consequent movement of cultural alternatives goes on so long that virtually all of the cultural boundaries eventually dissolve.

Discussion

Perhaps the most important lesson of the social influence model is that intuition is not a very good guide to predicting what even a very simple dynamic model will produce. The social influence model is very simple indeed. Its mechanism can be stated in a single sentence: with probability equal to their cultural similarity, a randomly chosen site will adopt one of the cultural features of a randomly chosen neighbor. That's it. Yet, it turns out to be very difficult to anticipate how the number of stable cultural regions varies as a function of the four parameters in the model. Two of the results were intuitively obvious, but two were not. The two results that were intuitive were that the number of stable regions increases with the number of possible traits that each cultural feature could take, and decreases with the range of interaction. The two counterintuitive results are that the number of stable regions decreases with more cultural features, and with large territories. The computer runs of the social influence model demonstrate that unaided intuition about how dynamic processes develop over time is not necessarily very reliable.

The social influence model also illustrates how new distinctions are suggested by a formal model. The model demonstrates that two different aspects of cultural complexity work in opposite directions. More cultural features lead to fewer stable regions, but more traits on each feature lead to more stable regions. Thus, in considering the complexity of a cultural system, one should distinguish between the number of different features and the number of traits that each feature can take.

The social influence model also suggests that functionalist explanations for common observations need not be the only or even the simplest ones. For example, suppose there are two equally attractive variants of a cultural practice, and the less common one vanishes over time. A functionalist explanation would be that those practicing the less common variant switched to the more common variant because there was some advantage in doing things the way most other people do. This makes good sense for problems of coordination, such as which side of the street to drive on, or which technical standard to employ (Lewis 1967; Saloner and Farrell 1986; Axelrod 1995). But, as we have seen, the social influence model demonstrates that even if there is no advantage to adopting the majority practice, the majority practice may still tend to drive the minority practice to extinction. The reason is that if neighbors following different practices are equally likely to switch to the other practice, the practice with the fewest followers is the one most likely to become extinct first. Thus the mere observation that a practice followed by few people was lost does not necessarily mean either that the practice had less intrinsic merit or that there was some advantage in following a more common practice. As in the social influence model, it could be that even unbiased changes in adherence lead to a less common practice disappearing simply because it is more vulnerable to random fluctuations in numbers of adherents.

The results of the social influence model suggest two other warnings about potentially false conclusions from empirical observations. Polarization occurs in the model even though the only mechanism for change is one of convergence toward a neighbor. Thus, when polarization is seen, it need not be due to any divergent process. Likewise, when cultural traits are highly correlated in geographic regions, one should not assume that there is some natural way in which those particular traits go together. The social influence model shows how homogeneous cultural regions can arise without any intrinsic relationship between the separate dimensions that become correlated.

The social influence model suggests new empirical questions and hypotheses. For example, the model predicts that large territories will actually have fewer stable regions than moderate-sized territories. I have been able to find only one relevant empirical study. This was a study of the number of languages on the various Solomon Islands (Terrell 1977). It found that islands with less than 100 square miles had a single language. Above that size, the number of languages increases about one for every 190-square-mile increment in island area. This is clearly a different result than predicted by the social influence model. Two reasons for the discrepancy are suggested by the empirical study itself: languages tend to diverge in large islands, and there is greater ecological diversity in large islands. The social influence model ignores both of these effects. Thus, a remaining unanswered question is what would happen to the number of distinct cultures as a function of territory when there is no systematic divergence, and when the territory is uniform.

Extensions of the Model

One advantage of a very simple model is that new things can be added without cluttering it up very much. The following are examples of potentially interesting extensions to the present model of social influence: cultural drift (modeled as spontaneous change in a trait), terrain effects (some pairs of adjacent sites less likely to interact than others), early geographic differences (nonrandom initial traits), status (some sites less likely to change than others), cultural attractiveness (some traits less likely to change than others), technological change (continuing introduction of new and more attractive traits), material basis for culture (interac-

tion between trait attractiveness and terrain), public education and broadcasting (some interactions come from widely disseminated messages), mobility,[11] organizational culture (substituting hierarchical for geographic neighborhoods), sociology of science (interaction among semi-isolated disciplines with drift, technological change, and organizational culture), and cultural divergence (interaction between dissimilar sites causing increasing cultural distance).

Perhaps the most interesting extension and, at the same time, the most difficult one to analyze is cultural drift. Cultural drift is involved in phenomena such as linguistic shifts and religious fragmentation. It could also be used to take account of the fact that there is always some chance that neighbors will affect each other no matter how different their cultures.

Although it is easy to introduce cultural drift, analyzing its full implications is challenging. In the original version of the model, the cultures in any given run eventually stop changing. This happens when every pair of neighboring sites have cultures that are either identical or completely different. When this occurs, the resulting cultural regions are stable, and the number of stable regions can be used as a measure of the heterogeneity of the population.

When cultural drift is introduced, however, social influence continues indefinitely and thus any regions that do form are not stable. This raises two questions about how to analyze the effects of cultural drift. The first question is: what is the best measure of the heterogeneity of the population when a simple count of stable regions cannot be used? The second question is: how long should a given run be allowed to go before the measurements are taken?

In answer to the first question, there are at least four plausible measures of heterogeneity of the population at any given time. Taking a local view, one could consider differences between all pairs of neighboring sites. Then one could either measure how many features differed between neighbors or count the number of neighboring pairs that had any differences. Alternatively, one could take a more global view and count the number of cultural regions or zones that existed at a given time, even though they were not stable.

In answer to the second question, there are two plausible ways to decide when the measurements should be taken. One way is to use a given amount of "historical" time, regardless of the number of sites in the territory. This would entail using a given number of expected activations per site. The other method would be to run the model until a selected measure of heterogeneity no longer changed very much over time. This would allow the necessary time for each territory to achieve an equilibrium between the forces of social convergence and the forces of cultural drift. This method would presumably require more "historical time" for large territories than small territories.

[11] The fact that larger neighborhoods result in fewer stable regions suggests that mobility will also result in fewer stable regions. This is confirmed in simulations using the present model reported by Axtell et al. (1996).

After a measure of heterogeneity and a duration method are selected, the model can be run with cultural drift. In particular, the effects of all the parameters can be studied and compared to their effects in the original model. These parameters include the number of cultural features, the traits per feature, the number of neighbors for each interior site, and the size of the territory. Preliminary analysis suggests the effects of changes in the parameters are quite complicated. For example, at a given rate of cultural drift, the effects of some of the parameters seem to depend on just which measure of heterogeneity is being used. Moreover, there are statistical interactions among the effects of the various parameters. Finally, a complete analysis would also require varying the rate of cultural drift as well as the parameters of the original model. In sum, it is not trivial to determine how the introduction of cultural drift affects cultural change in the present model of social influence.[12]

Conclusion

The proposed model shows how individual or group differences can be durable despite tendencies toward convergence. It treats culture as the attributes that social influence can influence. Unlike previous models of cultural change or social influence, this one is based on the interplay between different dimensions or features that characterize people. The basic assumption is that the opportunity for interaction and convergence is proportional to the number of features that two neighbors already share. Stable cultural differences emerge as regions develop in which everyone shares the same culture, but have nothing in common with the culture of neighboring regions.

The degree of polarization is measured by the number of different cultural regions that exist when no further change is possible. Theoretical and statistical analysis shows that polarization increases when there are few dimensions to the culture, when there are many alternative traits on each dimension, and when interactions are only with adjacent sites. Moreover, polarization is highest when the size of the territory is big

[12] For those wishing to explore this and other extensions of the model, the source code and documentation are available on the Internet at http://pscs.physics.lsa.umich.edu/Sofrware/ComplexCoop.html. At that site, use the link to "Disseminating Culture."

enough to allow for many cultures, but small enough for the change process to settle down before all cultural boundaries are dissolved by the spread of cultural traits.

The proposed model is unique not only in considering the interplay between different features of culture, but also in regarding each feature as having a whole set of alternatives. Previous models of social influence treat culture as either a continuous dimension or a single pair of alternatives. If culture is seen as a continuous dimension, then convergence tends to lead to homogeneity unless some other mechanism is introduced to prevent it. If culture is seen as one variable with a single pair of alternatives, only two possibilities are open. Even if a set of binary alternatives is allowed (e.g., Epstein and Axtell 1996), then the present model would yield no more than two different cultures among its stable regions.[13] Thus, to sustain cultural variety in the proposed model, there must be several dimensions to the culture, and each dimension must have more than two alternative traits.

The social influence model illustrates three fundamental points:

1. Local convergence can lead to global polarization.
2. The interplay between different features of culture can shape the process of social influence.
3. Even simple mechanisms of change can give counterintuitive results, as shown by the present model, in which large territories generate surprisingly little polarization.

The model suggests some interesting interpretations for the four topics mentioned at the start of the paper. Of course, a simple model can only be suggestive and can never be definitive.

1. *State formation.* Because the formation of a national state is facilitated by social convergence over a territory (Deutsch 1953 and 1969; Cederman forthcoming), the results of the model demonstrate how arbitrary the actual boundaries can be. For example, if the political process took hold at the historical era represented by the third panel of Figure 7-1, a state would be more likely to form in the relatively homogeneous southern part of the map than in the relatively heterogeneous northern part, even though there was initially nothing to distinguish north from south. In technical terms, the outcome is highly path dependent (e.g., Arthur 1988).

2. *Succession conflict.* Cultural assimilation of multinational states has turned out to be much harder than most observers had predicted before

[13] With two traits per feature, the only stable outcome would be for every site to have either the same culture or the complementary culture of each of its neighbors. Because the complement of a complement is the original culture, at most two different cultures would be possible among all the stable regions.

the breakup of the Soviet Union and Yugoslavia. The model of social influence offered here suggests how local interaction can lead to cohesive communities without actually leading to homogenization over large distances. The model helps explain how terrain that discourages long-distance interaction (as in the physically rugged territory of the Caucasus or of the former Yugoslavia) promotes small-scale homogeneity along with large-scale diversity.

3. *Transnational integration.*

a. The model throws an interesting light on the effect of centuries-long European expansion to dominate much of the globe. It is not surprising that increasing a cultural area homogenizes the newer additions to the old. It is more surprising that the old regions should homogenize internally. In other words, the model suggests that the expansion of European influence from the fifteenth century could help homogenize Europe itself.

b. With recent advances in transportation, mass media, and information technology, many interactions are now largely independent of geographical distance. With random long-distance interactions, the heterogeneity sustained by local interaction cannot be sustained.[14] An interesting corollary is that leaders of states can try to slow or eliminate the homogenization by cutting their citizens off from interactions with outsiders. Recently, however, the regimes of both Burma and North Korea have had second thoughts about the price to be paid for such isolation.

c. The model also throws light on the controversial thesis of Huntington (1993) that conflict in the future will largely be along the boundaries of very large cultural regions rather than between nations within the same cultural region. The results of the present model demonstrate that as the relevant political territory gets larger, the number of distinct cultural regions can be expected to decline, even in the absence of conquest.

4. *Social cleavages.*

a. Different levels of government performance in different regions of Italy have been traced to differences in civic traditions that date back 700 years (Putnam 1993, 121–62). The interesting addition to the model that these results suggest is that some stable civic cultures are more effective than others in promoting good government. This in turn suggests that the role of informal organizations as the basis of social capital and trust (Putnam 1995; Fukuyama 1995) can be analyzed in terms of how the processes of social influence can lead to uniformity over large areas without necessarily leading to complete homogenization.

b. The model gives the largest number of stable regions when there

[14] This result was confirmed with the present model by allowing every agent to interact with every other agent (Axtell et al. 1996).

are few cultural features and many traits per feature. This suggests that the hardest differences to resolve through social influence are those with few issues, but with many distinct possibilities for each issue. The surprising part of this conclusion is that having fewer issues causes such rapid local convergence that large-scale convergence may not occur.

c. In the near future, electronic communications will allow us to develop patterns of interaction that are chosen rather than imposed by geography. If individuals are linked together at random, one could expect substantial convergence over time. In the more likely case that the interactions will be based on self-selection, people will tend to interact with others who are already quite similar to them on relevant dimensions (Resnick et al. 1994; Abramson et al. 1988). An implication of the model is that such self-selection could result in an even stronger tendency toward both "local" convergence and global polarization. Only then the "local" convergence will be based not on geography, but on emergent patterns of more or less like-minded communication. The implications for resolving the tensions inherent in a multicultural society are problematic.

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